

**BACK TO BACK CONVERTER CONTROL TECHNIQUE  
USING MATLAB**

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**BACK TO BACK CONVERTER CONTROL TECHNIQUE  
USING MATLAB**

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**A thesis submitted in partial fulfillment of the  
requirements for the awarded of the Degree of Bachelor of Electrical &  
Electronic Engineering**

**Faculty of Electrical & Electronic Engineering  
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**NOVEMBER, 2010**

“I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power System)”

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UNIVERSITI MALAYSIA PAHANG

**BORANG PENGESAHAN STATUS TESIS♦**

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USING MATLAB**

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To my beloved mother and father..

Who always give me courage to finish this thesis.

Also, to those people who have guided and inspired me  
throughout my journey of learning. Thank you for the supports and advices  
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## **ABSTRACT**

Back to back converter circuit model is a cascade circuit that a combination of AC to DC rectifier and DC to AC inverter. The AC input source firstly will converted to DC by using a rectifier and then will converted back to AC by using an inverter. Some application that using back to back converter is such as variable speed wind turbine that employ wound rotor induction generator and also HVDC transmission system. Generally, this project can be divided into three parts that is modeling rectifier station, inverter station and the controller for both station.



## **ABSTRAK**

Pengubah arus terus kepada arus ulang alik dan pengubah arus ulang alik kepada arus terus boleh digabungkan menjadu satu pengubah yang boleh digunakan untuk pelbagai kegunaan. Sebagai contoh kegunaan pengubah ini ialah seperti sistem penghantaran arus terus bervoltan tinggi dan juga sistem turbin angin. Sumber arus ulang alik pada awalnya akan ditukar kepada arus terus menggunakan pengubah arus ulang alik kepada arus terus dan kemudian ditukar semula menjadi arus ulang alik dengan menggunakan pengubah arus terus kepada arus ulang alik. Umumnya, projek ini boleh dibahagikan kepada tiga bahagian iaitu pemodelan stesen pengubah arus ulang alik kepada arus terus, stesen pengubah arus terus kepada arus ulang alik dan juga pengawal untuk kedua-dua stesen pengubah.

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**LIST OF SYMBOLS**

V	-	Voltage
I	-	Current
Hz	-	Hertz
P	-	Real Power
Q	-	Reactive Power

**LIST OF ABBREVIATION**

HVDC	-	High Voltage Direct Current
DC	-	Direct Current
AC	-	Alternate Current
kV	-	Kilo Volt
kA	-	Kilo Ampere
P	-	Real Power
Q	-	Reactive Power
IGBT	-	Insulated Gate Bipolar Transistor

**LIST OF APPENDICES**

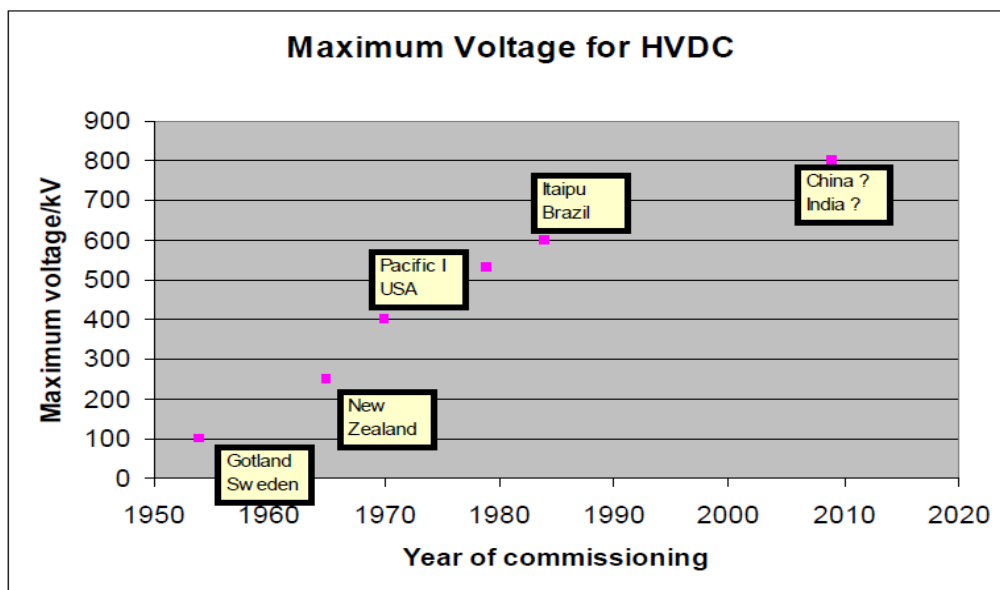
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## **CHAPTER I**

### **INTRODUCTION**

#### **1.1 Background**

During the latter part of the 19<sup>th</sup> century, electricity started to become increasingly important for society. The development of high-voltage-direct-current (HVDC) began in the mid 1920s. The first commercial HVDC Link carried power between the mainland of Sweden to the island of Gotland with 100V voltage level in 1954. Since then, the voltage and power level has been raised as shown in figure 1.1 in the next page[12];



**Figure 1.1** Development of HVDC[12]

High voltage direct current (HVDC) convert AC voltage to DC voltage in a rectifier and transmits DC power through the transmission line, and then reconverts DC into AC power in inverter and supplies the power. As a voltage, current and transmission power in the DC transmission can be controlled rapidly, when compared with the AC transmission, it is robust against a disturbance and increases a dynamic characteristic of AC power system and decreases a short-circuit capacity. The controllability of HVDC links is often cited as an important advantage of DC systems. This controllability can be valuable in improving the dynamic performance of large power systems. To achieve the promised advantages, control systems must perform appropriately for various disturbances and system condition. HVDC technology finds application in the transmission of power over long distances or by means of under water cable, and in the interconnection of differently managed power systems which may be operated synchronously or asynchronously[5].

Back to back converter is usually used in HVDC system that used widely in most of modern countries such as America and Japan. Back to back HVDC system also is very useful when two asynchronous AC systems need to be interconnecting. HVDC is used is for AC system stabilization reasons.

Because of HVDC nowadays is often used in most country, this project is about to study what is HVDC and to design and simulate one of few types of HVDC that is back to back HVDC link. Other types of HVDC will be discussed more in chapter 2. Back to back HVDC system is same with other type of HVDC. The only different is back to back is not for transmission. Both rectifier and inverter station is locate at the same place.

## **1.2 Objectives of the project**

The main objective of this project is to develop a model of back to back converter using MATLAB/SIMULINK that will be interfaced with HVDC transmission system. This HVDC is to connect the two different systems that operate with different frequencies.

## **1.3 Scope of the project**

The scopes of the project are:

- Design a back to back converter.
- Design the controller for inverter and inverter.
- Analysis about system fault in HVDC

## **1.4 Problem statement**

This project is focused on the design of back to back converter that is very important to improve the transmission system nowadays. There is a major problem in transmission system now that transmit in AC such as can't make interconnection with two systems with different frequency. AC transmission also has disadvantages that can be improved by HVDC such as to increase the capacity of an existing power grid, for power transmission stabilization and reducing losses.

## **1.5 Thesis outline**

This thesis contains five chapters. Chapter I is about the project which consists of background, objectives, scopes and overview of the whole chapter.

Chapter II provides a literature review on general about HVDC system. This chapter discusses about overview of HVDC system, configuration of HVDC systems, physical structure and advantage of HVDC system.

Chapter III focuses on methods that are being used including flow chart. The methods that are being discussed consist of overview of the Whole System, back to back HVDC system model, converter transformer, thyristor, converter control system and DC link. This chapter also shows some equations that are being used to get some parameters of components.

Chapter IV discusses all the results based on objectives while Chapter V covers the conclusion, problems encountered and future recommendations for this project.

## **CHAPTER II**

### **LITERATURE REVIEW**

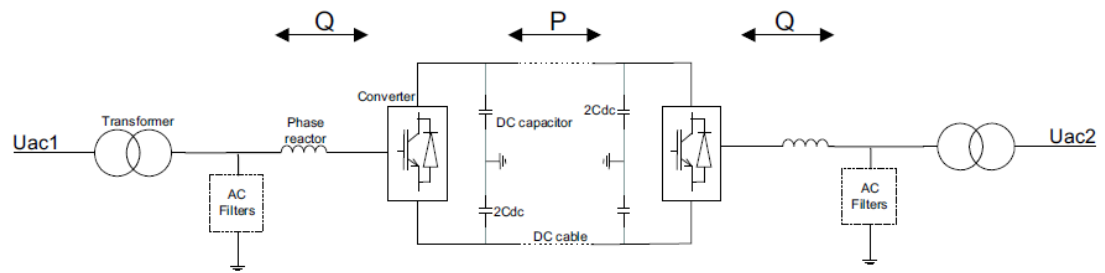
#### **2.1 Introduction**

This chapter presents an overview of high-voltage-direct-current (HVDC), and configuration, arrangement physical structure and the advantages of HVDC.

#### **2.2 Overview of High-Voltage-Direct-Current (HVDC).**

The power system begins from power plant. Inside the power plant, electrical power is producing by generator. From power plant, electrical power will transmit to transmission substation to step up by using transformer. From power plant to substation, the system operate in AC. HVDC is used at transmission line only. To convert AC to DC, rectifier is used. In the end of transmission line, inverter is used to convert DC to AC again. The next station is power substation. The electrical power will step down here and transmit to the load or user. The figure 2.1 shows the HVDC system in power transmission system[5].



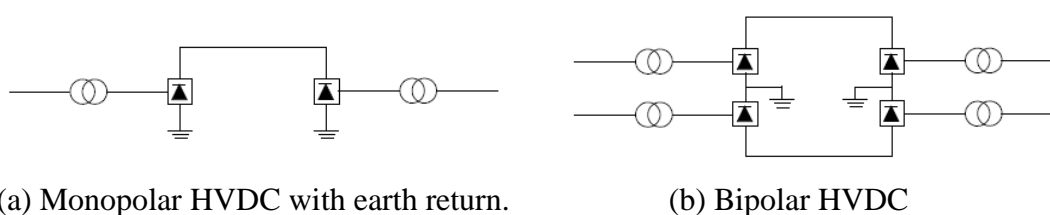


**Figure 2.1** HVDC system[2].

Figure 2.1 show that how HVDC operate in two systems. As we know, the DC have only real power(P) not reactive power(Q) and apparent power(S). In DC, the value of frequency is equal to zero. So, the unsynchronized of AC can be combined together when the system convert to DC. Figure 2 show that how two unsynchronized of AC that have different value of frequency (60Hz and 50Hz) can be connected when using the HVDC. To convert AC to DC, rectifier is used and to convert DC to AC, inverter is used. In DC, there are no reactive component like inductance and capacitance. Capacitance is leading (+ve) and inductance is lagging (-ve).From the figure, after generation, transformer is used to step up the voltage. Transformer is used in AC only because transformer is component of inductance. After HVDC transmission, electrical power will convert to AC and step down by using transformer again[2].

## 2.3 Configuration of HVDC systems

HVDC converter bridges and lines or cables can be arranged into a number of configurations for effective utilization. Converter bridges may be arranged either monopolar or bipolar as shown in Figure 2.2 and are described as follow:



**Figure 2.2** Monopolar and bipolar connection of HVDC converter bridges[1].

### 2.3.1 Monopolar HVDC system with earth return.

In monopolar links, two converters are used which are separated by a singlepole line and a positive or a negative dc voltage is used. In Figure 2.2 (a), there is only one insulated transmission conductor installed and the ground is used for the return current. For instance, the Konti-Skan(1965) project and Sardinia-Italy(mainland) (1967) project use monopolar links[2]. Instead of using the ground as a return path, a metallic return conductor may be used[1].

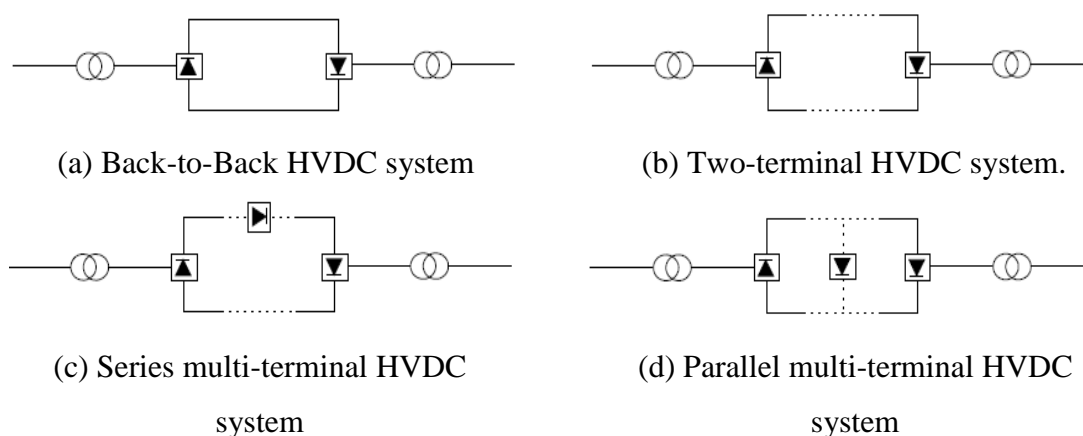
### 2.3.2 Bipolar HVDC

This is the most commonly used configuration of HVDC power transmission systems[2]. The bipolar circuit link, shown in Figure 2.2(b), has two insulated conductors used as plus and minus poles. The two poles can be used independently if both neutrals are grounded. It increases power transfer capacity. Under normal operation, the currents flowing in each pole are equal, and there is no ground current. In case of failure of one pole power transmission can continue on the other pole, so

its reliability is high. Most overhead line HVDC transmission systems are bipolar [1].

## 2.4 Arrangements of HVDC systems

The selection of configurations of HVDC system depends on the function and location of the converter stations. Various schemes and configurations of HVDC systems are shown in simplified form in Figure 2.3[3]:



**Figure 2.3** Arrangements of HVDC systems[1].

### 2.4.1 Back-to-Back HVDC system

In this case the two converter stations are located at the same site and no transmission line or cable is required between the converter bridges. The connection may be monopolar or bipolar. A block diagram of a back-to-back system is shown in Figure 2.3(a). The two ac systems interconnected may have the same or different nominal frequency, i.e. 50Hz and 60Hz (The back-to-back link can be used to transmit power between two neighboring non-synchronous systems). Examples of such system can be found in Japan and South America [15]. The dc voltage in this

case is quite low (i.e. 50kV -150kV) and the converter does not have to be optimized with respect to the dc bus voltage and the associated distance to reduce costs, etc[1].

#### **2.4.2 Two-terminal HVDC system.**

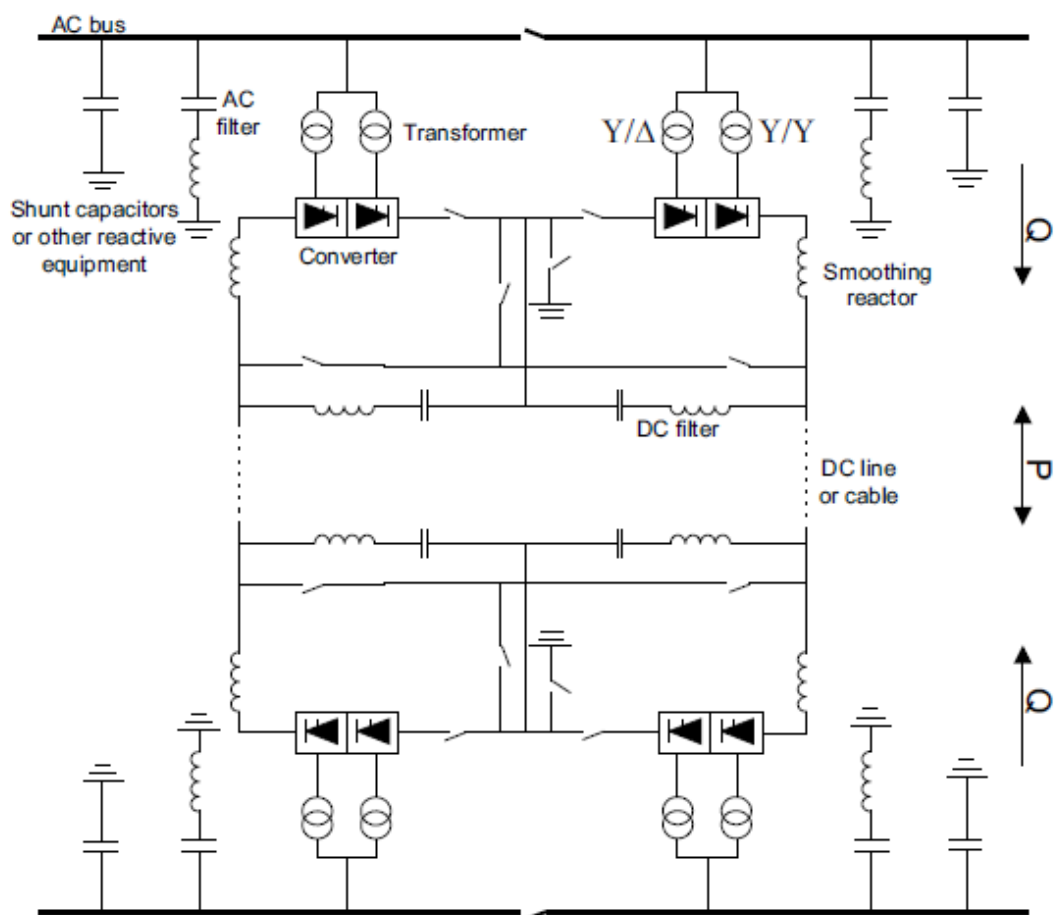
When it is economical to transfer electric power through dc transmission from one geographical location to another, a two-terminal or point-to-point HVDC transmission shown in Figure 2.3(b) is used. In other words, dc power from a dc rectifier terminal is transported to the other terminal operating as an inverter. This is typical of most HVDC transmission systems. The link may connect two non-synchronous systems (e.g. between Sweden and Denmark) or connect two substations within one interconnected system (e.g. between Sweden and Finland, or the Three-gorges to Shanghai link in China)[1].

#### **2.4.3 Multi-terminal HVDC**

When three or more HVDC substations are geographically separated with interconnecting transmission lines or cables, the HVDC transmission system is multiterminal. If all substations are connected to the same voltage then the system is parallel multi-terminal dc shown in Figure 2.3(d). If one or more converter bridges are added in series in one or both poles, then the system is series multi-terminal dc shown in Figure 2.3(c). A combination of parallel and series connections of converter bridges is a hybrid multi-terminal system. Multi-terminal dc systems are more difficult to justify economically because of the cost of the additional substations. Examples of multi-terminal HVDC were implemented in the connection Sardinia-Corsica-Italy(SACOI), the Pacific Intertie in the US and the connection Hydro Quebec-New England Hydro from Canada to the US[1].

## 2.5 Physical structure

A HVDC system operating in bipolar mode, shown in Figure 2.4, consists of ac filters, shunt capacitor banks or other reactive-compensation equipment, converter transformers, converters, dc reactors, dc filters, and dc lines or cables[4].



**Figure 2.4** Basic configuration for a HVDC system[4].

### 2.5.1 Converters

The HVDC converters are an HVDC system's hearts. They perform the conversion from ac to dc (rectifier) at the sending end and from dc to ac (inverter) at the receiving end. HVDC converters are connected to the ac system by means of converter transformers. The main components are the thyristor valves. The six pulse valve bridge as the basic converter unit of classic HVDC is used equally well for rectification and inversion. The inductance is normally in the form of a transformer. A 12 pulse converter bridge can be built by connecting two six pulse bridges in series or parallel. Each single bridge consists of a certain amount of series connected thyristors with their auxiliary circuits. The bridges are then connected separately to the ac system by means of converter transformers, one of Y-Y winding structure and another Y- $\phi$  winding structure. In this way the 5th and 7th harmonic currents through the two transformers are in opposite phase. This significantly reduces the distortion in the ac system due to the HVDC converters[6].

### 2.5.2 Transformers

The transformers connect the ac network to the valve bridges, and adjust the ac voltage level on the rectifier terminals to a suitable level based on the dc voltage used for the transmission. The transformers can be of different design depending on the power to be transmitted, and possible transport requirements. The most common type is a single- phase-three-winding design. The windings on network side are connected in star. The windings on converter side are connected in star for one converter and in delta for the other converter. Three identical transformers are then needed per converter[4].

### **2.5.3 Ac-side Harmonic Filters**

The HVDC converters produce current harmonics on the ac side, these harmonics are prevented from entering into the connected ac network by ac filters. For example, on the ac side of a 12-pulse HVDC converter, current harmonics of the order of 11, 13, 23, 25 and higher are generated. Filters are installed in order to limit the amount of harmonics to a level allowed by the network. In the conversion process the converter consumes reactive power which is compensated in part by the filter banks and the rest by capacitor banks. [7].

### **2.5.4 Dc filters**

The HVDC converters produce ripple on the dc voltage. Voltage ripple in the frequency band between a few hundred Hz and a few kHz causes interference to telephone circuits near the dc line. Therefore, specially designed dc filters are used in order to reduce the ripple. Usually no dc filters are needed for pure cable transmission nor for Back-to-Back HVDC stations. However, it is necessary to install dc filters if an overhead line is used in part or all of the transmission system. The filters needed to take care of the harmonics generated on the dc end, are usually considerably smaller and less expensive than the filters on the ac side. Both passive and active dc filters can be used. In active filters power electronics is used to compensate the harmonic distortion. In modern installations active dc filters are used. Active filters are considered more flexible than passive filters, and become cheaper than passive filters for more complex tasks[8].

### **2.5.5 HVDC cables or overhead lines**

HVDC cables are normally used for submarine transmission. No serious length limitation exists for HVDC cables. For a back to back HVDC system, no dc cable or overhead line is needed. For connections over land, overhead lines are typically used. However the tendency is to also move to cables for connections over land, due to environmental concerns[4].

### 2.5.6 Smoothing reactor

Functions of the dc smoothing reactor include the following[2]:

- I. To prevent consequent commutation failures in the inverter by limiting the rate of increase of direct current during commutation in one bridge when the direct voltage of another bridge collapses.
- II. To decrease the incidence of commutation failures in the inverter during dips in alternating voltage.
- III. To decrease harmonic voltages and currents in the dc line.
- IV. To smooth the ripple in the direct current sufficiently to prevent the current from becoming discontinuous or almost so at light loads.
- V. To limit current in the bypass valves or bypass pair due to discharge of the shunt capacitances of the dc line and terminal equipment in the event that all the bypass valves or pairs on one pole are fired simultaneously.
- VI. To limit the crest current in the rectifier due to a short circuit on the dc line.
- VII. To prevent resonance of the dc circuit at the power frequency.

### 2.5.7 Control of HVDC Systems

The power transmitted over the HVDC link is controlled through the control system where one of the converters controls the dc voltage and the other converter controls the current through the dc circuit. The control system acts through firing angle adjustments of the valves and through tap changer adjustments on the converter transformers to obtain the desired combination of voltage and current. The control systems of the two stations of a bipolar HVDC system usually communicate with each other through a telecommunication link[1].

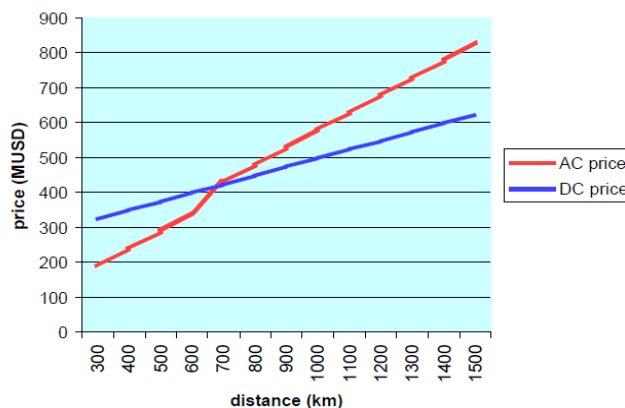


## 2.6 Advantage of HVDC system

The advantage of HVDC is the ability to transmit large amounts of power over long distances with lower capital costs and with lower losses than AC. Depending on voltage level and construction details, losses are quoted as about 3% per 1000 km. High-voltage direct current transmission allows efficient use of energy sources remote from load centers. The other advantages are[4]:

- I. Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
- II. Power transmission and stabilization between unsynchronized AC distribution systems
- III. Stabilizing a predominantly AC power-grid, without increasing maximum prospective short circuit current
- IV. Reducing line cost. HVDC needs fewer conductors as there is no need to support multiple phases. Also, thinner conductors can be used since HVDC does not suffer from the skin effect
- V. Facilitate power transmission between different countries that use AC at differing voltages or frequencies

However, HVDC is only practical if the energy that needs to transfer is over than 700km. For transmission low than 700KM, we prefer to use AC transmission. This point is called break-even distance. The graph as shown in figure 2.5 show us the distance should be considered for cost saving[4].



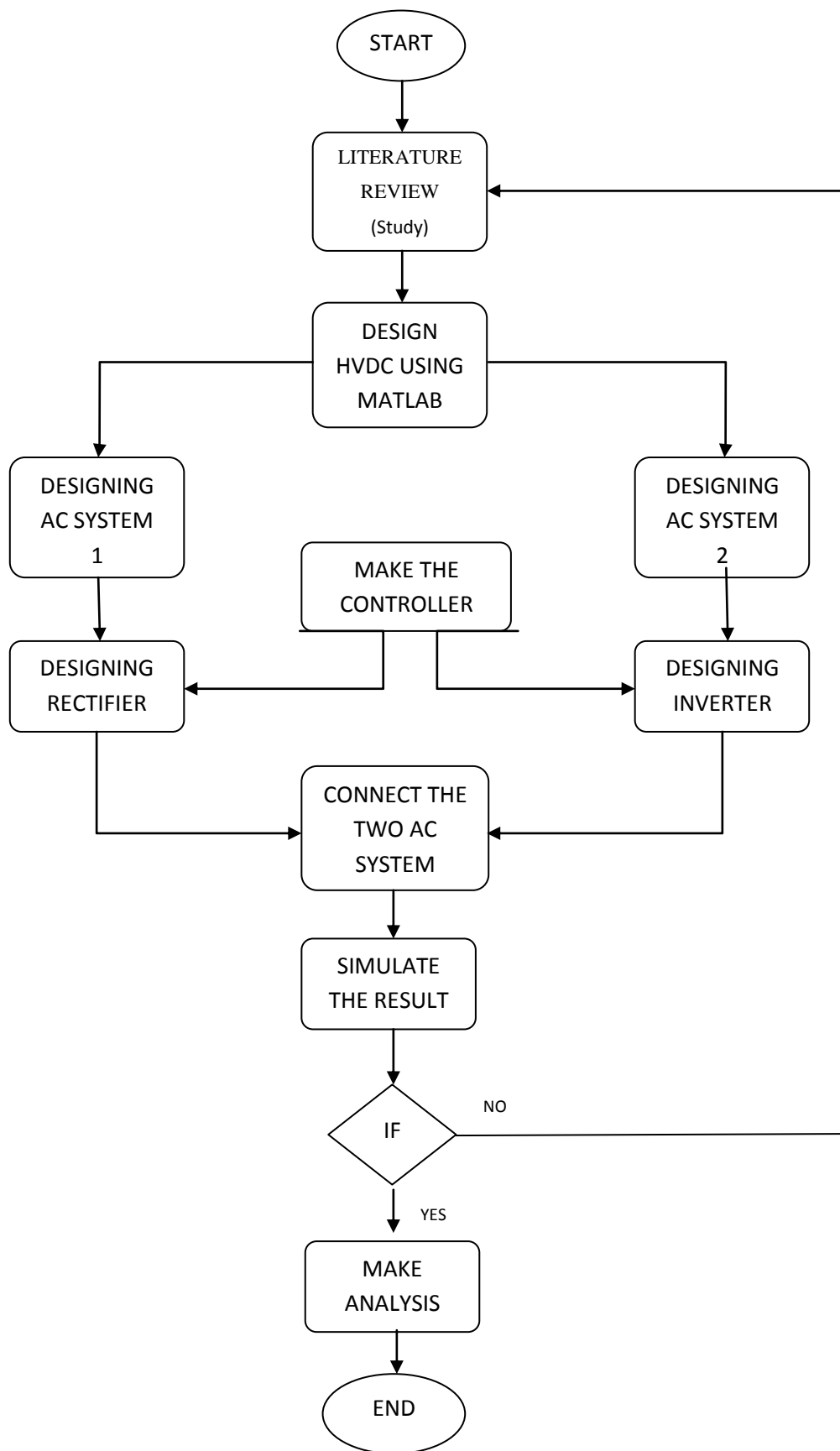
**Figure 2.5** Break-even distance[5]

## **CHAPTER III**

### **METHODOLOGY**

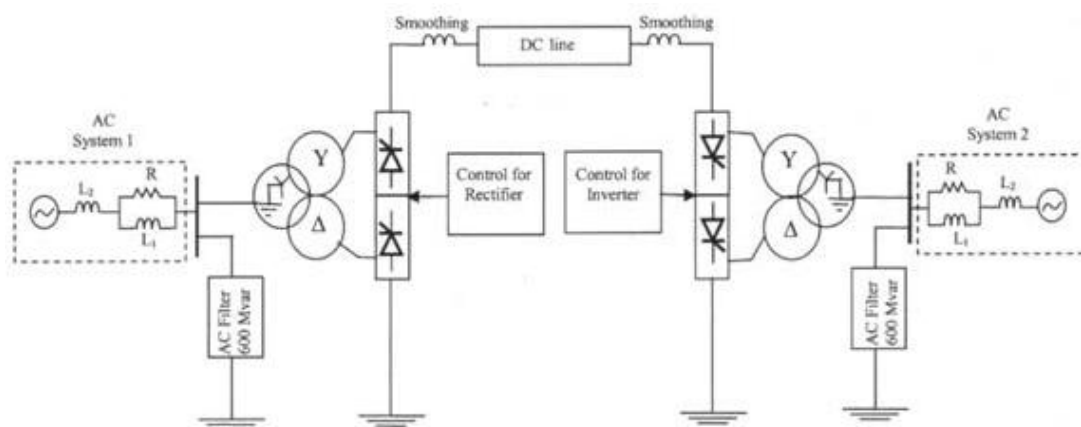
#### **3.1 Introduction**

This chapter discusses about the methods that are used for this project. It includes overview of the whole system and how the design of HVDC is made in this project including two AC networks with different frequency, converter transformer, converter (inverter station and rectifier station), and controller of both converter station and DC link. This designing is made by using MATLAB/SIMULINK.



**Figure 3.1** Flow Chart

## 3.2 Overview of the Whole System



**Figure 3.2** Simplified circuit of HVDC link

### 3.2.1 Back to back HVDC system model

The simplified circuit of HVDC shown in figure 3.2 has been used as a basis for the development.

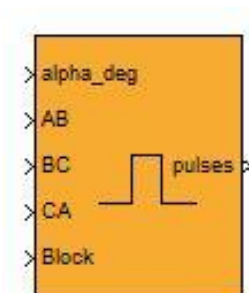
The HVDC system modeled using the Simulink package, is based on a point to- point DC transmission system. The DC system is a monopolar, 12 pulse converter using two universal bridge connected in series, rated 360 MW (6kA, 60 kV) at the inverter. DC interconnection is used to transmit power from a 230 kV,60 Hz network (system\_1) to 300 kV, 50 Hz network (system\_2).

**Table 3.1** Parameter in AC network

	AC system 1	AC system 2
Voltage supply (V)	230kV	300kV
Frequency (Hz)	60Hz	50Hz

As we can see from the table above, the voltage supply and frequency is applied different. To make the connection between these two systems, it is impossible to connect in AC. This is one of the purposes that back to back HVDC system that is for interconnection of two different frequency AC network.

### 3.2.2 Rectifier station control system

**Figure 3.3** Synchronized 6-Pulse Generator

Synchronized 6-Pulse Generator is used to generate pulse for rectifier station. Because of in rectifier station, thyristor is chosen as power switch, this pulse generator is suitable to control it. About the rectifier station, it will be discussed more in chapter 4.

The DC link voltage is maintained by using a synchronous 6 pulses generator at the rectifier station as shown in figure 3.6 above. Input 1 (alpha\_deg) is the alpha firing signal, in degrees. This input can be connected to a Constant block, or it can be connected to a controller system to control the pulses of the generator. Inputs 2(AB), 3(BC), and 4(CA) are the phase-to-phase synchronization voltages  $V_{ab}$ ,  $V_{bc}$ , and

Vca. The synchronization voltages should be in phase with the three phase-phase voltages at the AC terminal at network 1. Input 4(block) allows you to block the operation of the generator. The pulses are disabled when the applied signal is greater than zero.

This controller performs its task by generating a control voltage, which then controls the firing pulses, at some delay angle  $\alpha$ , to the rectifier valves. The relationship between DC current  $I_d$  and delay angle  $\alpha$  is obtained by using the expression for the DC voltage at the rectifier, which is given by:

$$V_{dr} = V_{dor} \cos(\alpha) - R_{cr} I_d \quad (3.1)$$

where  $V_{dr}$  is DC line voltage,  $V_{dor}$  is open circuit rectifier DC voltage, and  $R_{cr}$  is equivalent resistance of rectifier.

For constant  $I_d$ , and small changes in  $\alpha$

$$\frac{\Delta V_{dr}}{\Delta \alpha} = -V_{dor} \cdot \sin(\alpha) \quad (3.2)$$

The relationship between DC current and  $\alpha$  is given by:

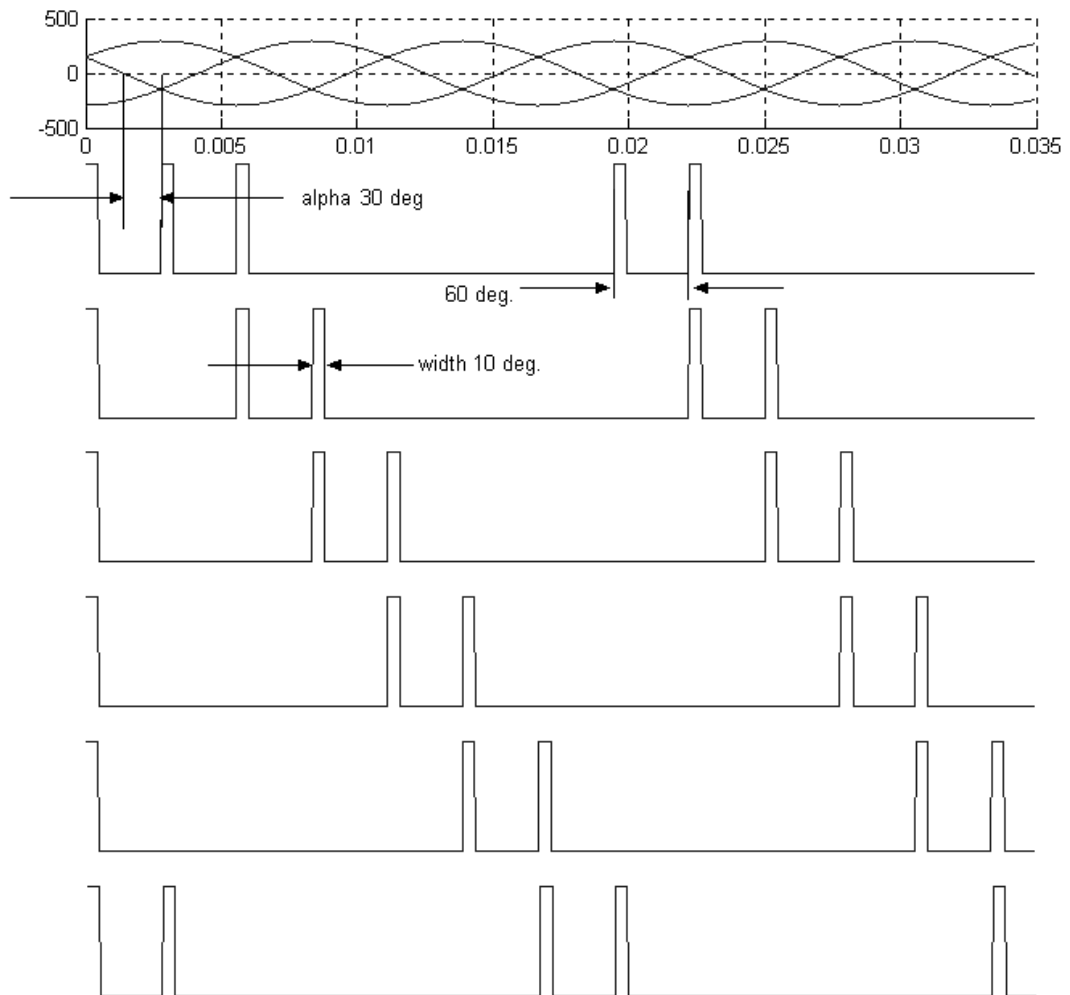
$$I_d = \frac{V_{dor} \cdot \cos(\alpha) - V_{doi} \cdot \cos(\gamma)}{R_{dc} + R_{cr} - R_{ci}} \quad (3.3)$$

where  $V_{doi}$  is open circuit inverter DC voltage,  $\alpha$  is rectifier firing (delay) angle,  $\gamma$  is inverter extinction angle,  $R_{dc}$  is DC line resistance, and  $R_{ci}$  is equivalent resistance of inverter.

The Synchronized 6-Pulse Generator block can be used to fire the six thyristors of a six-pulse converter. The output of the block is a vector of six pulses individually synchronized on the six thyristor voltages. The pulses are generated  $\alpha$  degrees after the increasing zero crossings of the thyristor commutation voltages.

The Synchronized 6-Pulse Generator block can be configured to work in double-pulsing mode. In this mode two pulses are sent to each thyristor: a first pulse when the  $\alpha$  angle is reached, then a second pulse 60 degrees later, when the next thyristor is fired.

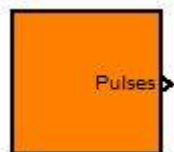
The figures below display the synchronization of the six pulses for an  $\alpha$  angle of 30 degrees and with double-pulsing mode. Notice that the pulses are generated 30 degrees after the zero crossings of the line-to-line.



**Figure 3.4** Pulse waveform generated by pulse generator



### 3.2.3 Inverter station control system

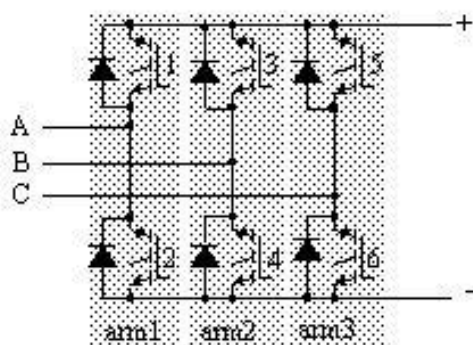


**Figure 3.5** Discrete PWM Generator

It is different for inverter station is aspect of control system. The controller that being used is discrete PWM generator. This is because at inverter station, the power switch is insulated gate bipolar transistor (IGBT). So the suitable controller that can be use is PWM generator.

The PWM Generator block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can be used to fire the self-commutated devices (FETs, GTOs, or IGBTs) of single-phase, two-phase, three-phase, two-level bridges or a combination of two three-phase bridges.

To fire the self-commutated devices of a three-arm bridge, 3-arm bridge (6 pulses) was selected. Pulses 1, 3, and 5 fire the upper devices of the first, second, and third arms. Pulses 2, 4, and 6 fire the lower devices.

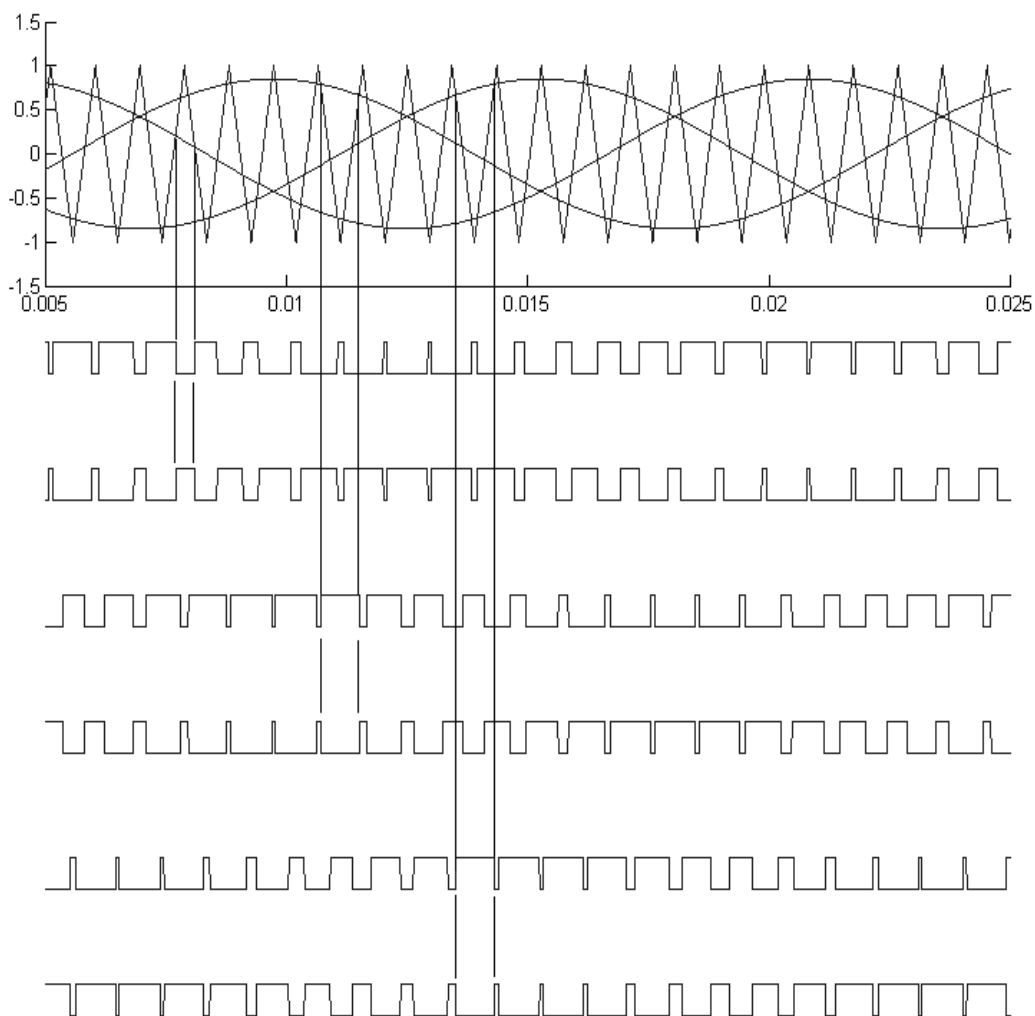


**Figure 3.6** Internal connection of 6 pulses insulated gate bipolar transistor (IGBT)

In this project, the inverter that being use is Double 3-arm bridges (12 pulses) IGBT. To fire the self-commutated devices of two six-pulse bridges connected in a twelve-pulse bridge configuration. The first six pulses (1 to 6) fire the six devices of

the first three-arm bridge and the last six pulses (7 to 12) fire the six devices of the second three-arm bridge.

The following figure displays the six pulses generated by the PWM Generator block when it is programmed to control a three-arm bridge.



**Figure 3.7** Pulse waveform generated by pwm generator

The triangular carrier signal is compared with the sinusoidal modulating signal. When the modulating signal is greater than the carrier pulse 1 is high (1) and pulse 2 is low (0). For a three-phase six-arm bridge the three modulating signals used for bridge 2 are the negative of the modulating signals applied to bridge 1.

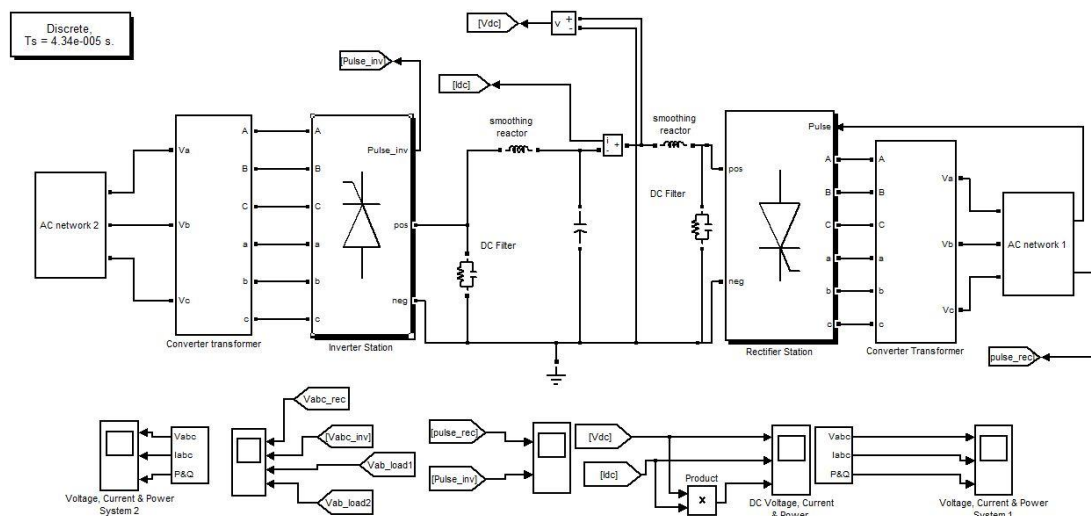
## CHAPTER IV

### RESULT AND DISCUSSION

#### 4.1 Introduction

This chapter discusses about all the result and discussion obtained from simulation of modeled back to back HVDC. This chapter also discussed the result about analysis about system fault in HVDC.

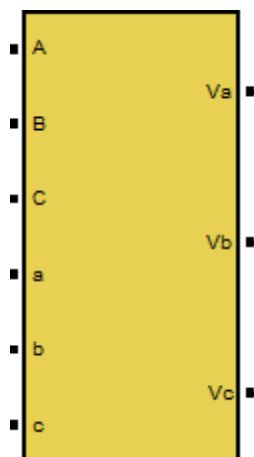
#### 4.2 System modeling



**Figure 4.1** Modeled Back to back HVDC system using MATLAB

Figure 4.1 above show the modeled back to back HVDC system. The system is operating with two different frequencies for two AC network. In AC network 1, the system is using 60Hz frequency and for AC network 2, the system is using 50Hz frequency.

### 4.3 Converter Transformer

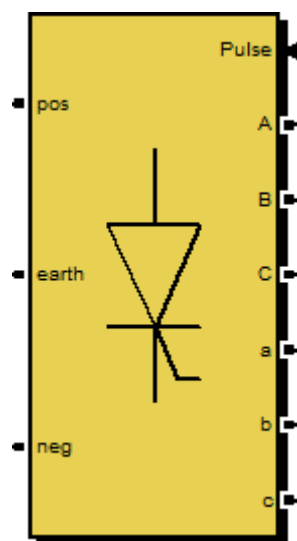


**Figure 4.2** Masked three phase transformer block

The 60 MVA converter transformer (Wye grounded/Wye/ Delta) is modeled with three-phase transformer (Three-Windings) before entering rectifier station and after entering the inverter station. To enter the rectifier station, from AC system 1, the voltage is set 230kV. So, the voltage is going step down from 230kv to 70kV. The DC voltage in the intermediate circuit can be selected freely at HVDC back-to-back stations because of the short conductor length. The DC voltage is as low as possible, in order to build a small valve hall. So the voltage needs to step down before entering the rectifier station. For this reason at HVDC back-to-back stations valves with the highest available current rating are used.

After the DC voltage through inverter station, that mean the voltage is back to AC. The voltage is need to step up back before enter AC network 2. In this project, the AC network 2 is set 300kV with 50 Hz frequency. So, the transformer is setting to step up the voltage to 300kV from 70kV. When the voltage is same, the connection can be connect without any problem that can effect AC network 2.

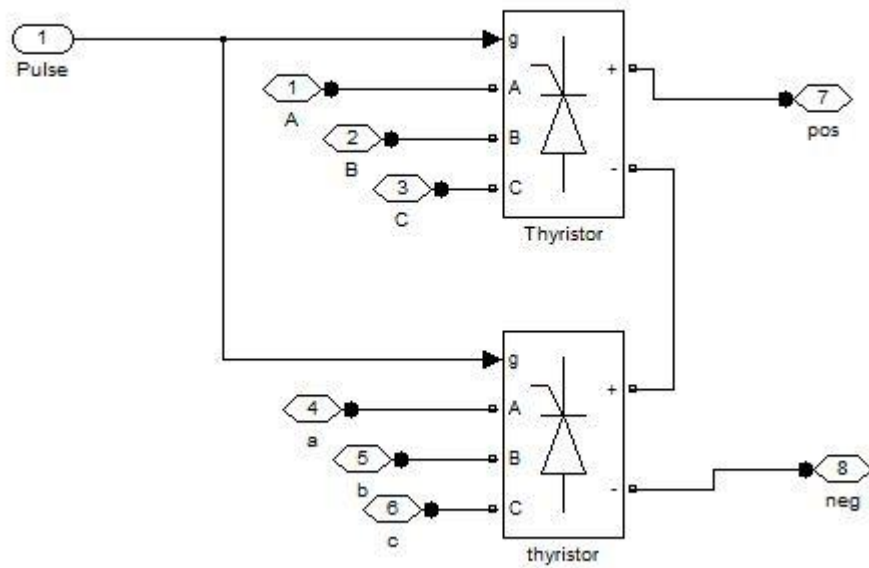
#### 4.4 Rectifier station



**Figure 4.3** Masked rectifier station block

Since modern thyristors can switch power on the scale of megawatts, thyristor valves have become the heart of high-voltage direct current (HVDC) conversion either to or from alternating current. Nearly all HVDC power converters with thyristor valves are assembled in a converter bridge of twelve pulse configuration.

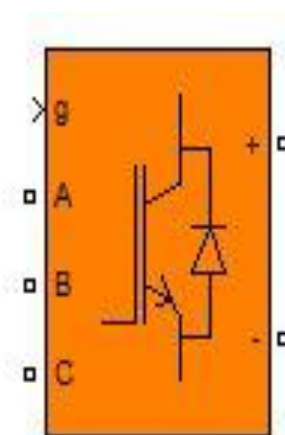
In this project, 12 pulses Thyristor Bridge is used for rectifier station by arranging two 6 pulse thyristors bridge. Figure below show the connection between two 6 pulse generator.



**Figure 4.4** Unmasked rectifier station block

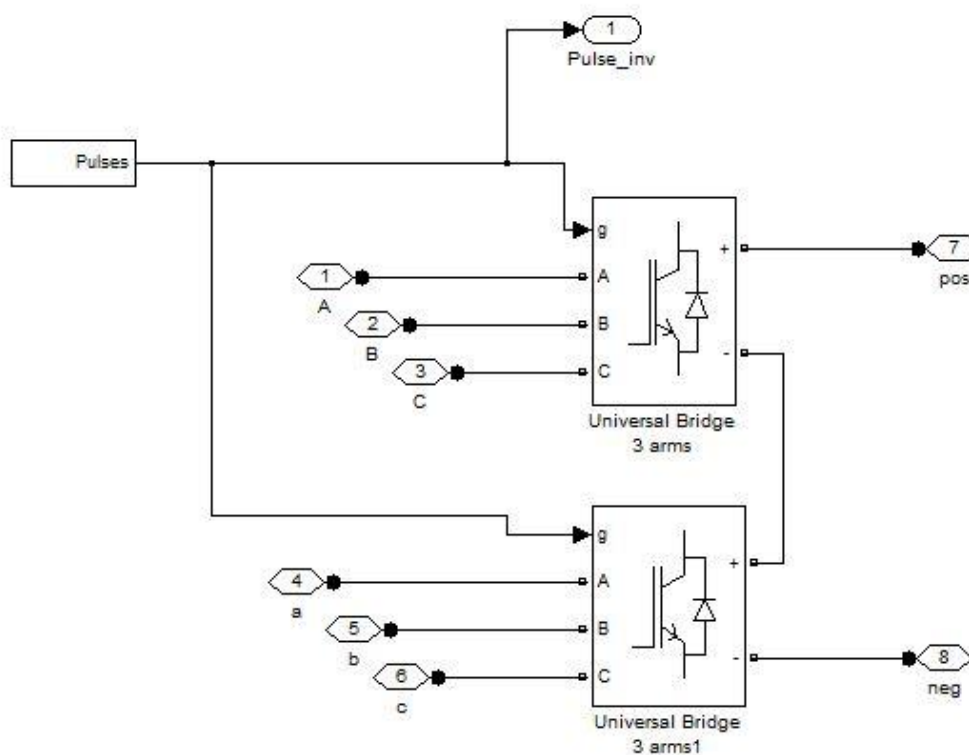
The input Pulse is came from converter controller that generates pulse for the thyristor. The pulse generated is about to control both thyristor. For the rectifier station, six other input for thyristor is the voltage supply that come from two converter transformer as mentioned in sub-topic 3.2.2 and the output that exit is in DC.

## 4.5 Inverter station



**Figure 4.5** 6 pulses insulated gate bipolar transistor (IGBT)

For the inverter station, the system opposite from the rectifier station, the input is become output and the output is become input. But for inverter station, the converter that being used in this project is two 3 arms bridge insulated gate bipolar transistor (IGBT). The connection of two 3 arms bridge insulated gate bipolar transistor (IGBT) is as shown in figure 4.6 below.



**Figure 4.6** Unmasked inverter station block

## 4.6 DC link

DC link is the connection between rectifier station and inverter station. After the electricity is being rectified, the electricity will trough DC link before enter the inverter station. DC link is consist of DC filter,smoothing reactor DC link capacitor. This three components is needed in order to get smooth DC Voltage and current. It is important to get smooth DC before entering inverter station. Inverter station need to get smooth DC for inverting process.

### 4.61 DC filter

The DC filter used is active filter and it consist of resistor and capacitor arranging in paralell. The parameter of the DC filter is as in table 3.2 below:

### 4.62 Smoothing reactor

Smoothing reactor is also important to get smooth DC. The function of smoothing reactor is as mention in chapter 2. For this project, the value of smoothing reactor is 200uH. See figure 4.1 in the next chapter to know the location of smoothing reactor.

### 4.63 DC link capacitor

DC link capacitor is use in DC link

The equation DC link capacitor is given by:

$$\frac{1}{\omega_o} C_{dc} \frac{dV_{dc}}{dt} = I_{Edc} - I_{Bdc} \quad (4.1)$$

Multiplying bothsidesof(15) by  $V_{dc}$  gives:

$$V_{dc} \frac{1}{\omega_o} C_{dc} \frac{dV_{dc}}{dt} = V_{dc} I_{Edc} - V_{dc} I_{Bdc} \quad (4.2)$$



The instantaneous powers at the ac and dc terminals of each converter are equal, giving power balance equation:

$$V_{dc} I_{Edc} = V_{Eshd} I_{Ed} + V_{Eshq} I_{Eq} \quad (4.3)$$

$$V_{dc} I_{Edc} = V_{Bshd} I_{Bd} + V_{Bshq} I_{Bq} \quad (4.4)$$

Equation (2) can therefore, be rewritten as:

$$\frac{1}{\omega_o} C_{dc} \frac{dV_{dc}}{dt} = \frac{1}{V_{dc}} [V_{Eshd} \quad V_{Bshd}] \begin{bmatrix} I_{Ed} \\ I_{Eq} \end{bmatrix} - \frac{1}{V_{dc}} [V_{Bshd} \quad V_{Bshq}] \begin{bmatrix} I_{Bd} \\ I_{Bq} \end{bmatrix} \quad (4.5)$$

Where,  $V_{dc}$  = Voltage at dc link

$V_{Eshd}$  = Voltage at ac system 1

$I_{Ed}$  = Current at ac system 1

$V_{Bshd}$  = Voltage at ac system 2

$I_{Bd}$  = Current at ac system 2

**Table 4.1** Parameter in DC link

	Component	Value
DC filter	Resistor ( $\Omega$ )	0.1 $\Omega$
	Capacitor (F)	1nF
Smoothing reactor	Inductor (H)	200 $\mu$ H
DC link capacitor	Capacitor (F)	0.5F

#### 4.7 Simulation result for stable system

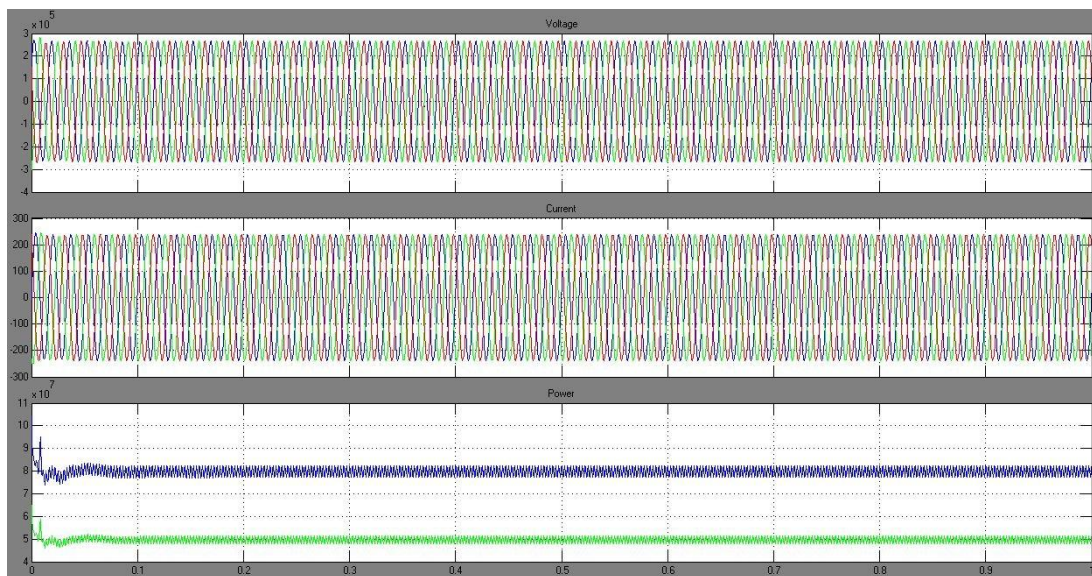


Figure 4.7 Voltage, current and power at AC network 1

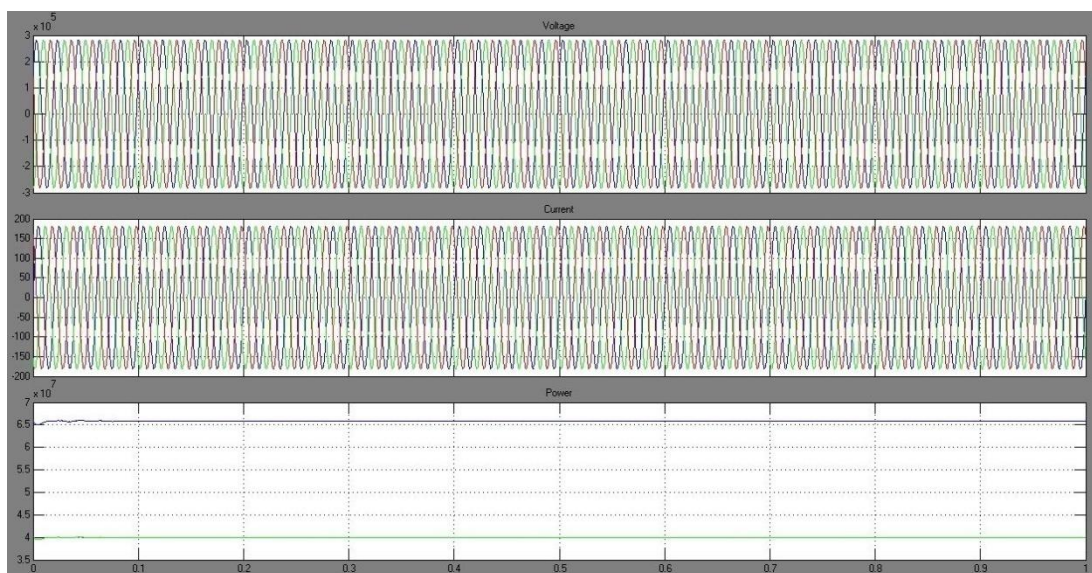
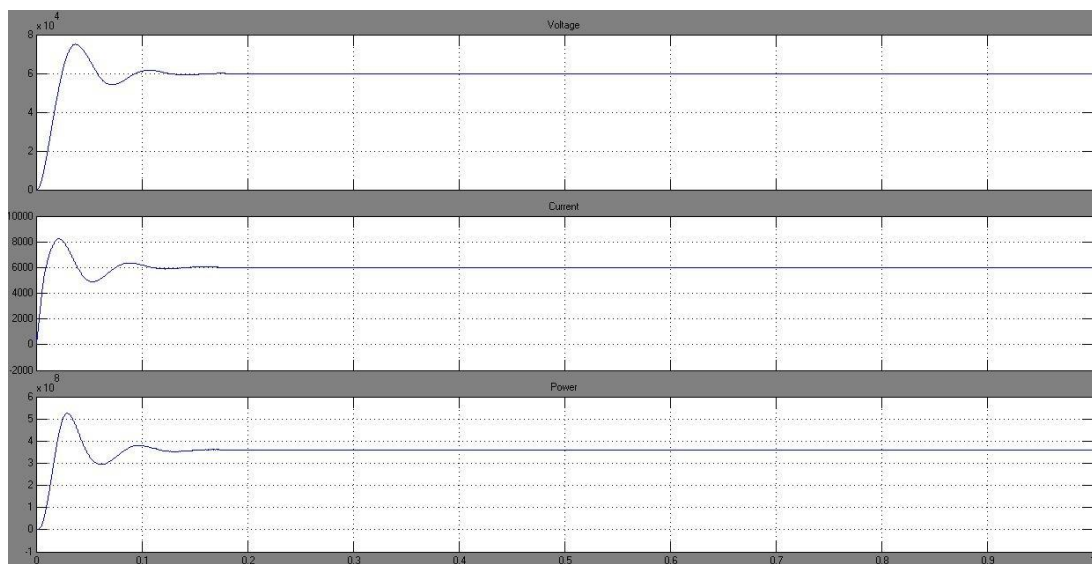


Figure 4.8 Voltage, current and power at AC network 2



**Figure 4.9** Voltage, current and power at DC link

Figure 4.7, figure 4.8 and figure 4.9 above is the result for stable system. Back to back converter consists of two converters that are rectifier and inverter. From AC network 1, the voltage source supply 230kV AC and current 237 A AC and generate active power and reactive power 80 MW and 50 MVar. Then after rectified, the rated voltage, current and power become 60 kV, 6 kA and 360 MW. After that, the DC is invert back to AC using inverter. The final AC voltage, current, active power and reactive power is become 300 kV, 180 A, 65 MW and 40 MVar. All the given voltage, current and power above is as table 4.2 below:

**Table 4.2** Simulation result for stable system

	AC network 1	DC link	AC network 2
Voltage (V)	230 kV	60kV	300 kV
Frequency (Hz)	60 Hz	0	50 HZ
Current (I)	237 A	6kA	180 A
Active power (P)	80 MW	360MW	65 MW
Reactive power (Q)	50 MVar	-	40 MVar

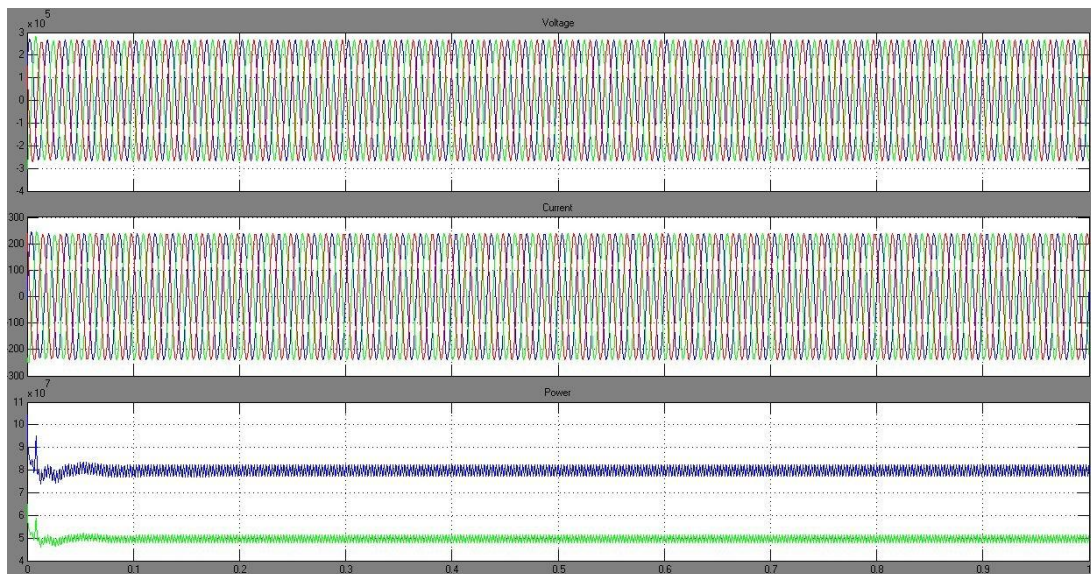
## **4.8 Simulation result for fault system**

Faults on the power system are the ultimate cause of momentary interruptions, voltage sags and voltage swells. Any measures taken to reduce the likelihood of a fault will help reduce the incidence of sags and interruptions to customers. These measures can include using underground circuits, tree trimming, and increased application of surge arresters for lightning protection on distribution circuits. On transmission circuits where lightning may be the most prevalent cause of faults, reducing tower footing resistances is one of the measures that can improve the lightning performance of lines.

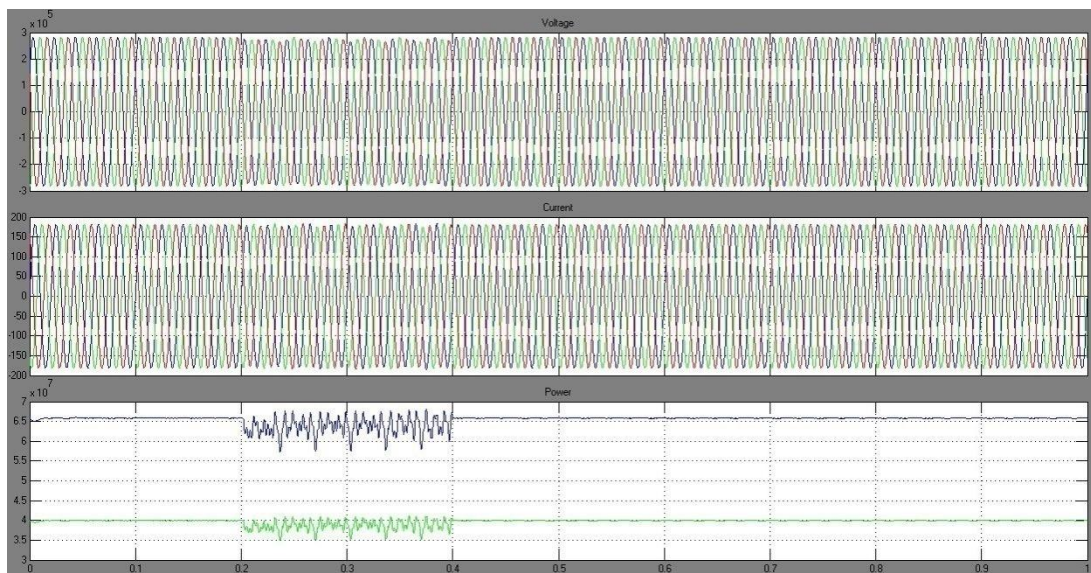
Based on theory, interconnection of two systems with different frequency is for protection for each system if one of the systems has trouble like fault happen. This mean, if fault happen in system 1, system 2 will not affected.

### **4.81 Fault in AC network 2**

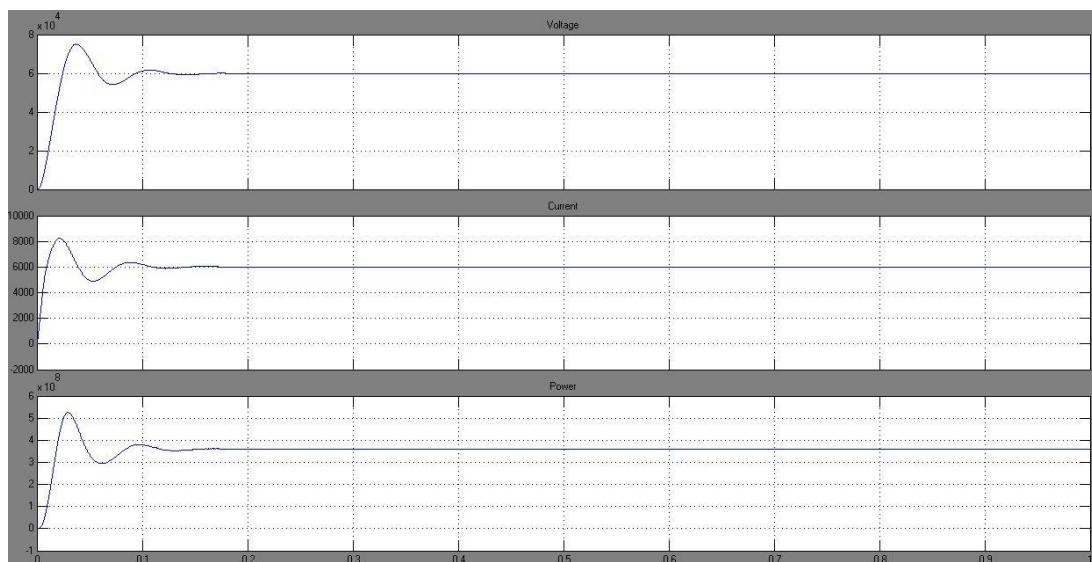
This subtopic is discuss about system fault at AC network 2. The fault means that any faults that happen that may give trouble for load in AC network 2. The fault time may be long or short period of time. For this simulation, the fault that happens is short period at 0.2s to 0.4s. This fault will cause the circuit breaker trip. So this interruption will affect the load. So during 0.2s to 0.4s, AC network 1 will cover the interruption. The result is as shown in figure 4.10, 4.11 and 4.12 below.



**Figure 4.10** Voltage, current and power at AC network 1



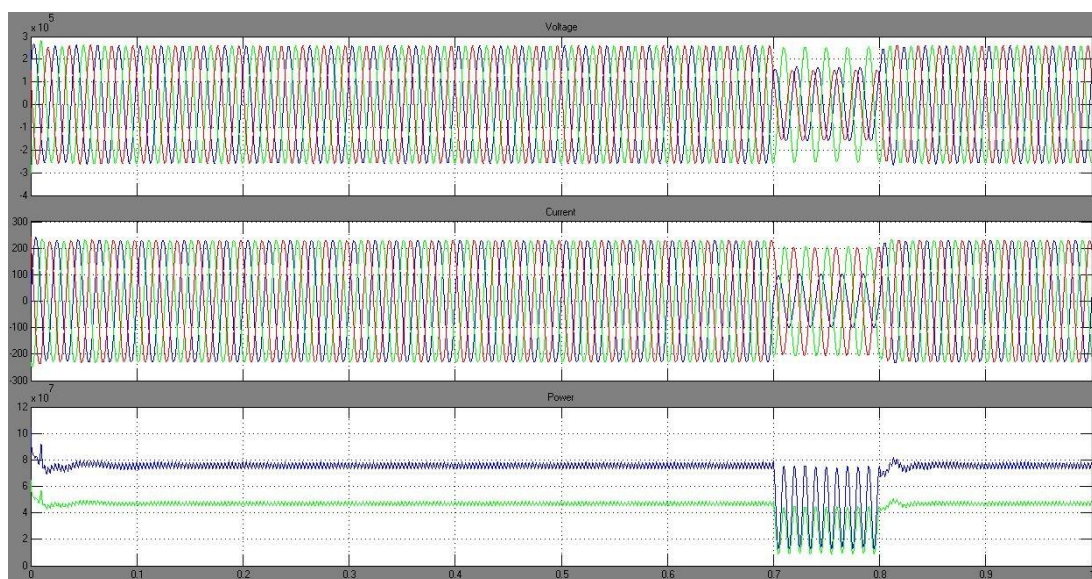
**Figure 4.11** Voltage, current and power at AC network 2



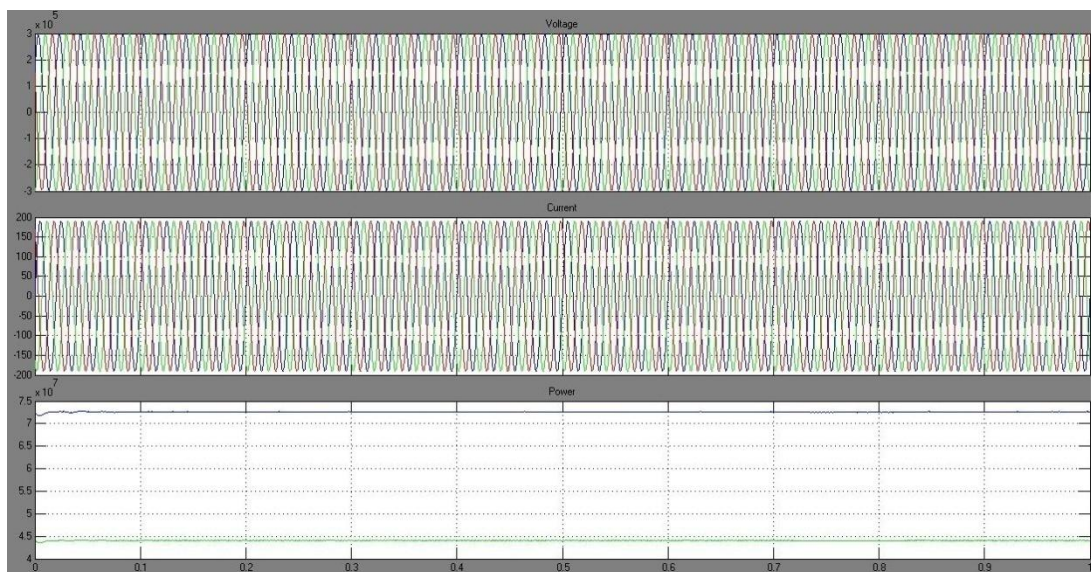
**Figure 4.12** Voltage, current and power at DC link

#### 4.82 Single phase to ground fault

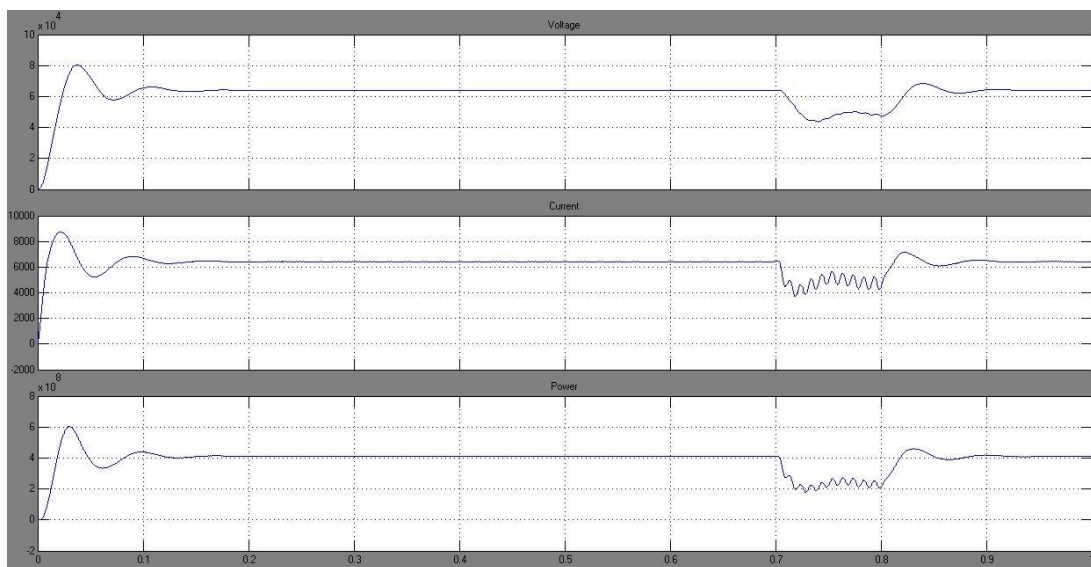
This fault is happen at phase a in AC network 1. The duration is set at 0.7s to 0.8s. This fault just effect to AC network 1 but not to AC network 2. Figure 4.13, 4.14 and 4.15 below will show the result.



**Figure 4.13** Voltage, current and power at AC network 1



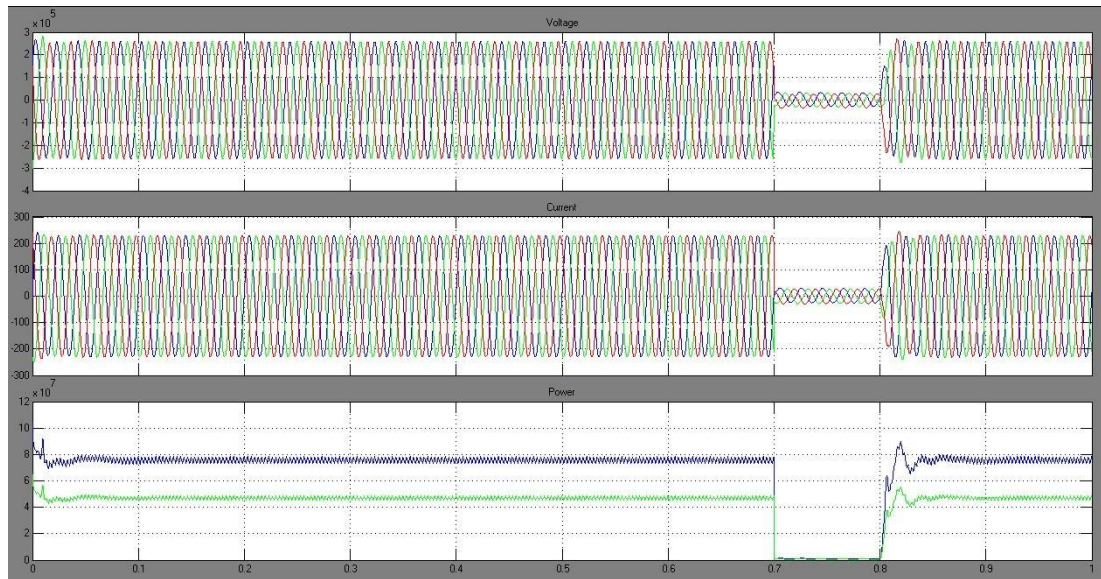
**Figure 4.14** Voltage, current and power at AC network 2



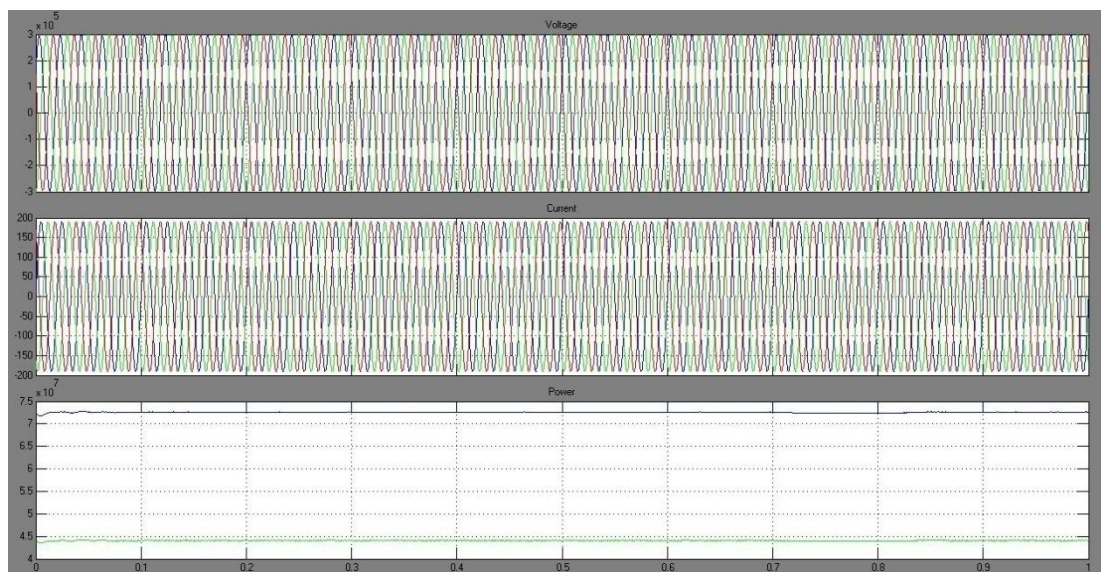
**Figure 4.15** Voltage, current and power at DC link

### 4.83 Three phase to ground fault

This fault is happen at phase a, b and c in AC network 1. The duration is set at 0.7s to 0.8s. This fault just effect to AC network 1 but not to AC network 2. Figure 4.16, 4.17 and 4.18 below will show the result.

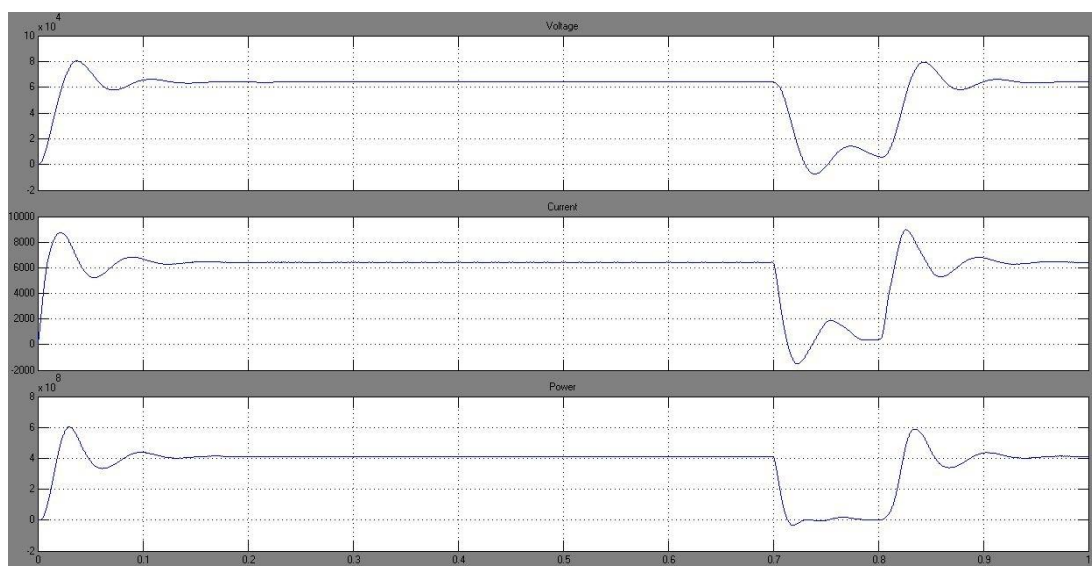


**Figure 4.16** Voltage, current and power at AC network 1



**Figure 4.17** Voltage, current and power at AC network 2



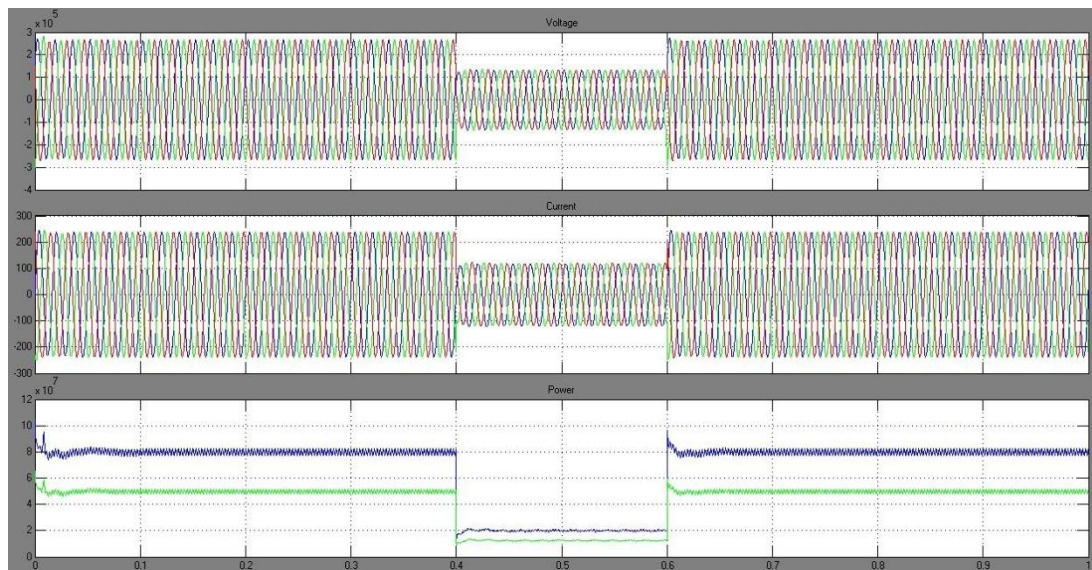


**Figure 4.18** Voltage, current and power at DC link

#### 4.84 Voltage sag

Voltage sags are caused by abrupt increases in loads such as short circuits or faults, motors starting, or electric heaters turning on, or they are caused by abrupt increases in source impedance, typically caused by a loose connection.

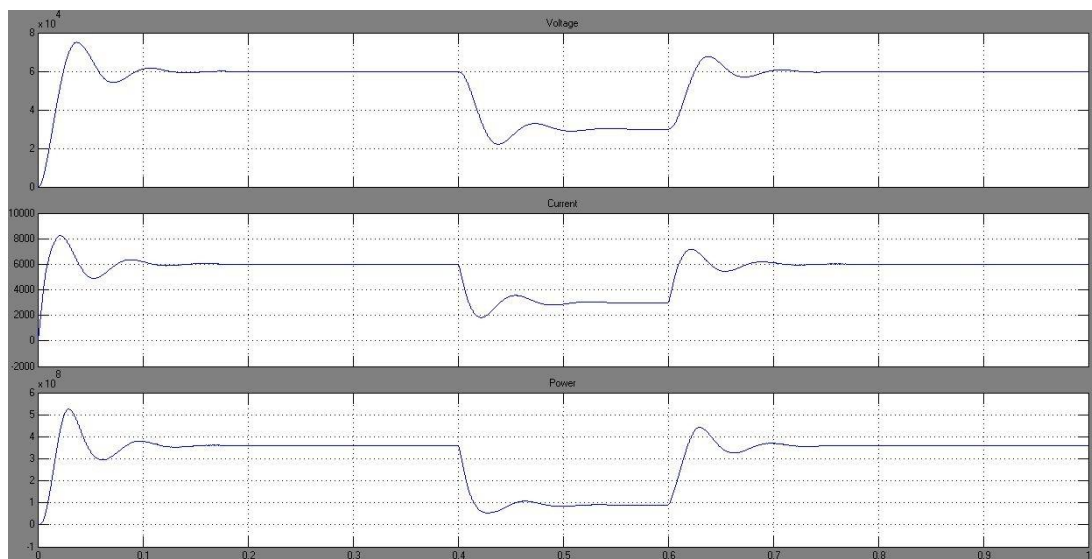
For this simulation, voltage sage is occur at AC network 1 for duration 0.2s starting from 0.4s to 0.6s. The result for voltage sag in system 1 and the other system is as shown in figure 4.19, figure 4.20 and figure 4.21.



**Figure 4.19** Voltage, current and power at AC network 1 on voltage sag condition



**Figure 4.20** Voltage, current and power at AC network 2 on voltage sag condition

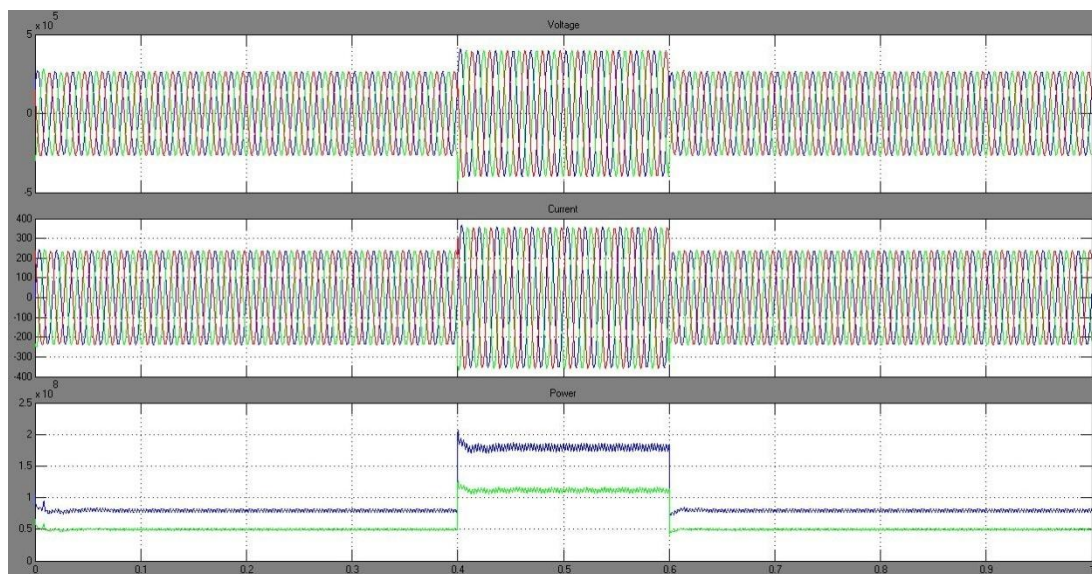


**Figure 4.21** Voltage, current and power at DC link on voltage sag condition

#### 4.85 Voltage swell

Voltage swells are almost always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection.

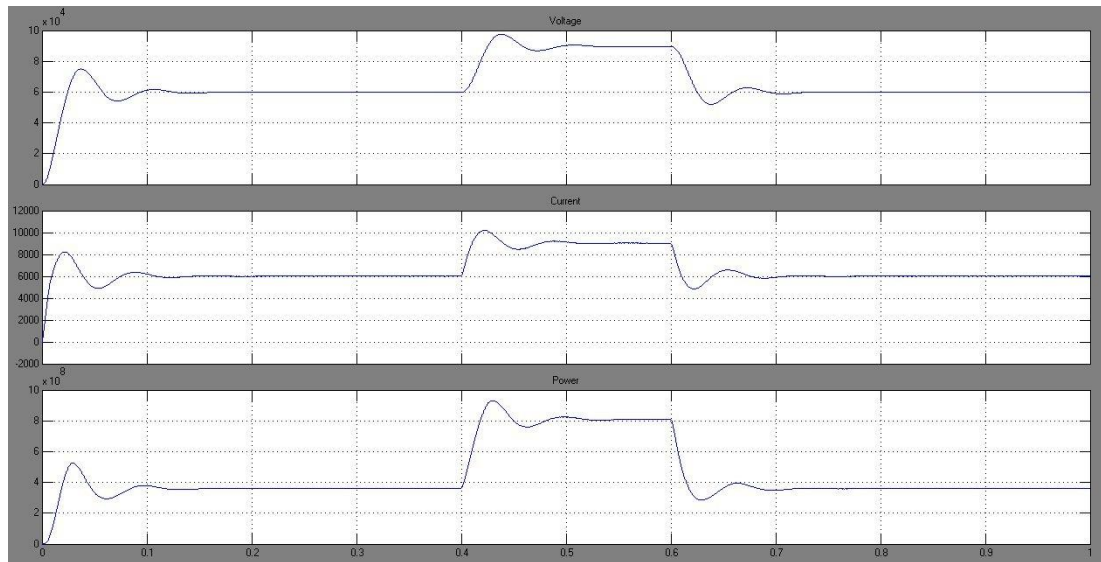
For this simulation, voltage swell is occur at AC network 1 for duration 0.2s starting from 0.4s to 0.6s. The result for voltage swell in system 1 and the other system is as shown in figure 4.22, figure 4.23 and figure 4.24.



**Figure 4.22** Voltage, current and power at AC network 1



**Figure 4.23** Voltage, current and power at AC network 2



**Figure 4.24** Voltage, current and power at DC link

## **CHAPTER V**

### **CONCLUSION & RECOMMENDATION**

#### **5.1 Conclusion**

The main objective of this project is to develop a model of back to back converter using MATLAB/SIMULINK that will be interfaced with HVDC system. the system must be the interconnection of two different AC system with different frequency.

Generally, overall of the objectives and scopes of project have been successfully achieved and the system is running properly as desired. The system is running as the theory that has been learn that is fault that occur in one of the system will not affected the other system.

Hopefully, this project can be a platform for other student to come up with more advance simulation that consider about system protection or something else that can make HVDC become more simple and effective.

### 5.2.1 Problem Encountered

In carrying this project, there is a problem that had been encountered such as

- hard to get smooth direct current.
  - The direct current is the output from rectifier and for early result is not really smooth and it affects the result for AC system 2. The solution is to put the smoothing reactor and DC capacitor. The parameter of these two components must be exactly perfect in order to get the smooth output direct current.
  
- Output from inverter is not perfect sinusoidal
  - At first, the inverter station is using thyristor same as rectifier station. The getting result not as desired. As a solution, the thyristor has been change to insulated gate bipolar transistor(IGBT). After change the power switch for inverter, the output result is more perfect.

### 5.3 Future development

The development of HVDC nowadays is very fast because almost all big electrical company in the world makes research and still not stops in making research. As has been discussed in chapter 1, the voltage level of HVDC is increase years by years. The development is about the converter must be a priority. Since now, the research that still in progress such as about the converter to improve the switching that produce less harmonic and also the voltage level for the converter. Maybe in future, HVDC will become the major transmission method in every country. The only problem that been facing now to built HVDC station is about cost. In future, maybe the cost will be decrease because the more advance power switch can be develop.

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## APPENDIX A

### Coding for GUI

```

8% PROJEK SARJANA MUDA
clc,clear,close all

mohdamri=menu('PROJEK SARJANA MUDA',...
              'BACK TO BACK CONVERTER CONTROL TECHNIQUE USING MATLAB',...
              'CLOSE');

mohdamri1=num2str(mohdamri);
switch mohdamri1

    case '1',

        mohdamri2=menu('HIGH VOLTAGE DIRECT CURRENT',...
                        'VOLTAGE STABLE',...
                        'SINGLE PHASE FAULT TO GROUND',...
                        'THREE PHASE FAULT TO GROUND',...
                        'VOLTAGE SAG',...
                        'VOLTAGE SWELL',...
                        'RETURN');

        mohdamri3=num2str(mohdamri2);
        switch mohdamri3

            case '1',Voltage_Stable;
            case '2',singlephasefault;
            case '3',threephasefault;
            case '4',Voltage_Sag;
            case '5',Voltage_Swell;
            case '6',clc,MERI,close all
        end

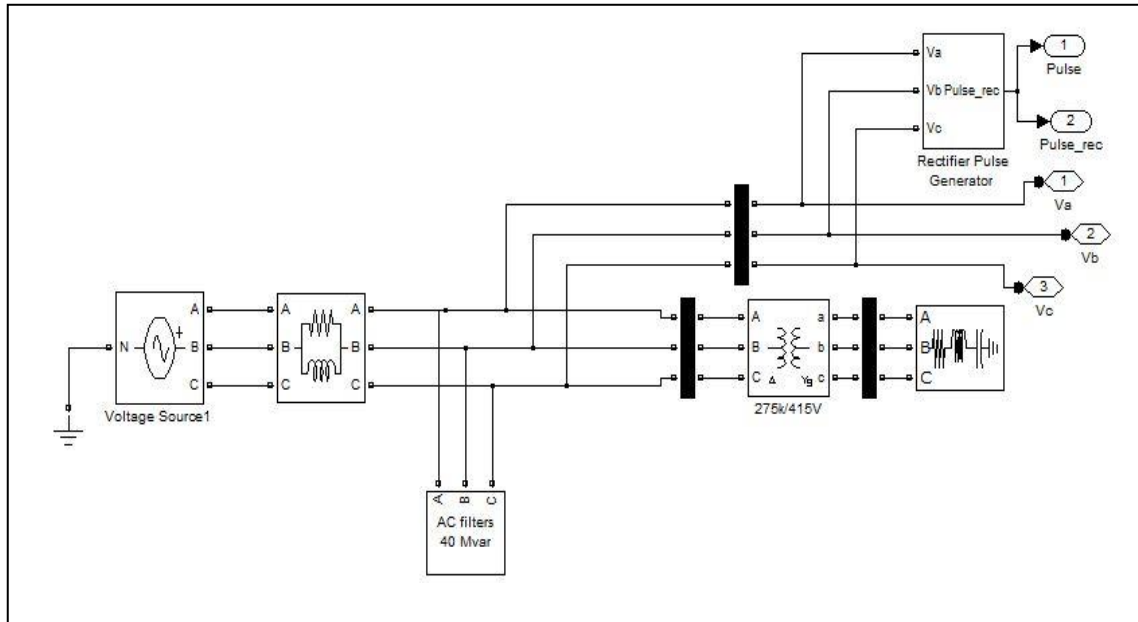
    case '2',clc,clear, break

end

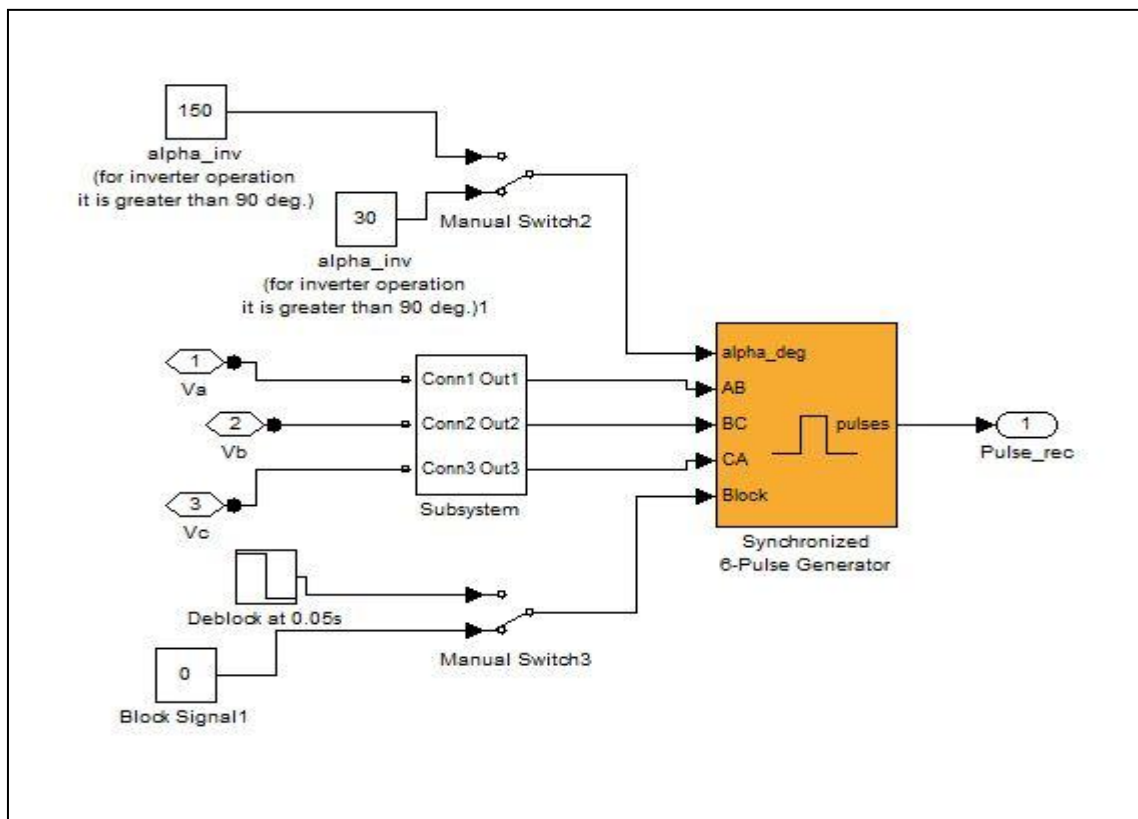
```

APPENDIX B

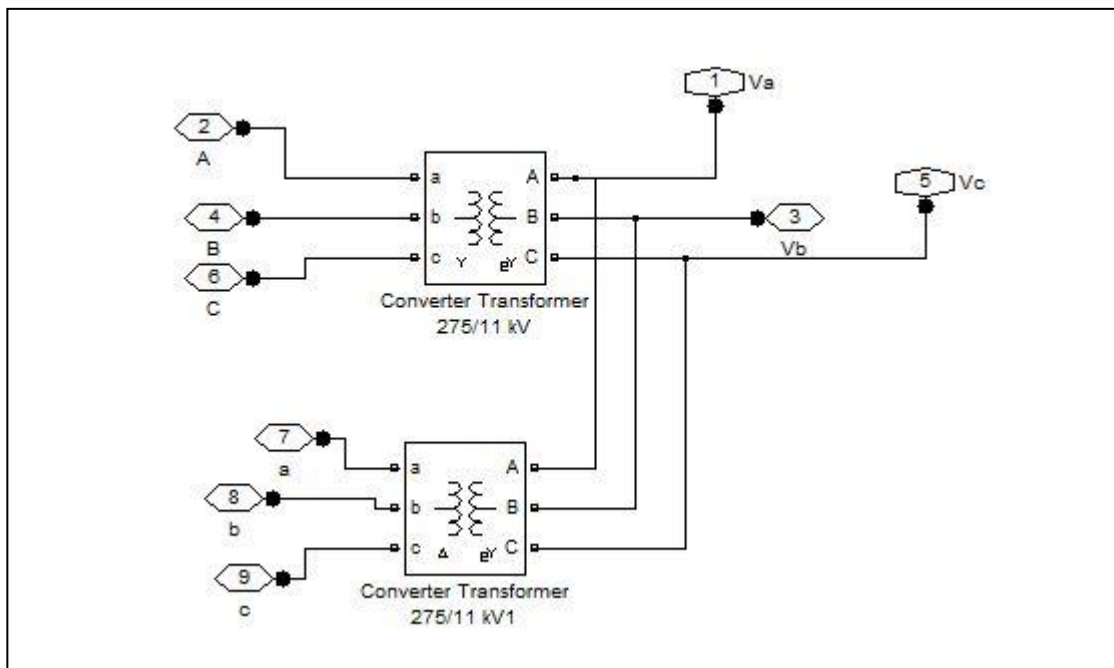
UNMASK SUBSYSTEM FOR MASKED BLOCK



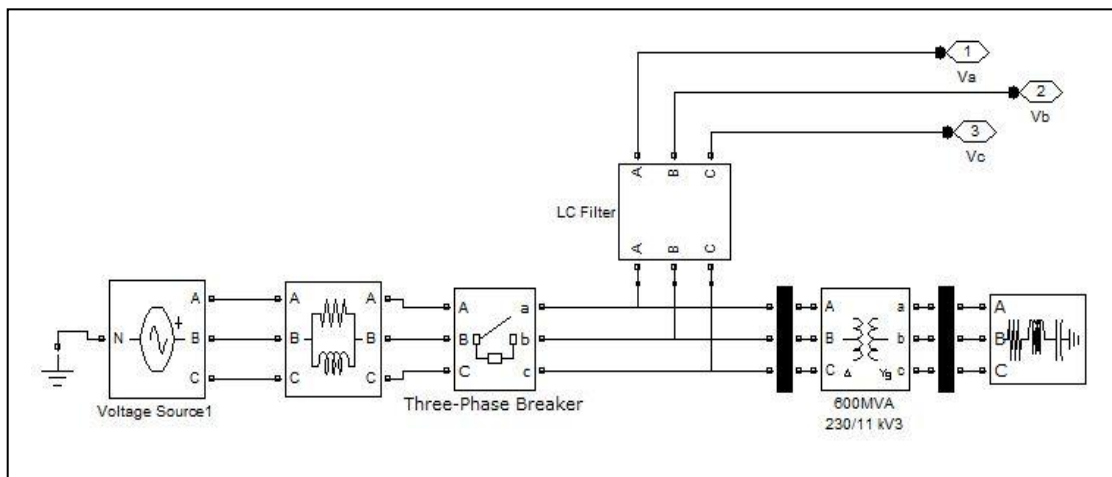
AC network 1



Rectifier pulse generator



Converter Transformer



AC network 2

## APPENDIX C

### BLOCK PARAMETER

Block Parameters: Voltage Source1

Three-Phase Programmable Voltage Source (mask) (link)

This block implements a three-phase zero-impedance voltage source. The common node (neutral) of the three sources is accessible via input 1 (N) of the block. Time variation for the amplitude, phase and frequency of the fundamental can be pre-programmed. In addition, two harmonics can be superimposed on the fundamental.

Note: For "Phasor simulation", frequency variation and harmonic injection are not allowed. Specify Order = 1 and Seq=1,2 or 0 to inject additional fundamental components A and B in any sequence.

Parameters

Positive-sequence: [ Amplitude(Vrms Ph-Ph) Phase(deg.) Freq. (Hz) ]  
[230e3 0 60]

Time variation of: Amplitude

Type of variation: Step

Step magnitude (pu, deg. or Hz):  
0

Variation timing (s) : [ Start End ]  
[0 0.14]

Fundamental and/or Harmonic generation:

OK Cancel Help Apply

Voltage source at AC network 1

Block Parameters: Three-Phase Series RLC Load2

Three-Phase Series RLC Load (mask) (link)

Implements a three-phase series RLC load.

Parameters

Configuration: Y (grounded)

Nominal phase-to-phase voltage Vn (Vrms)  
415

Nominal frequency fn (Hz):  
60

Active power P (W):  
100e6

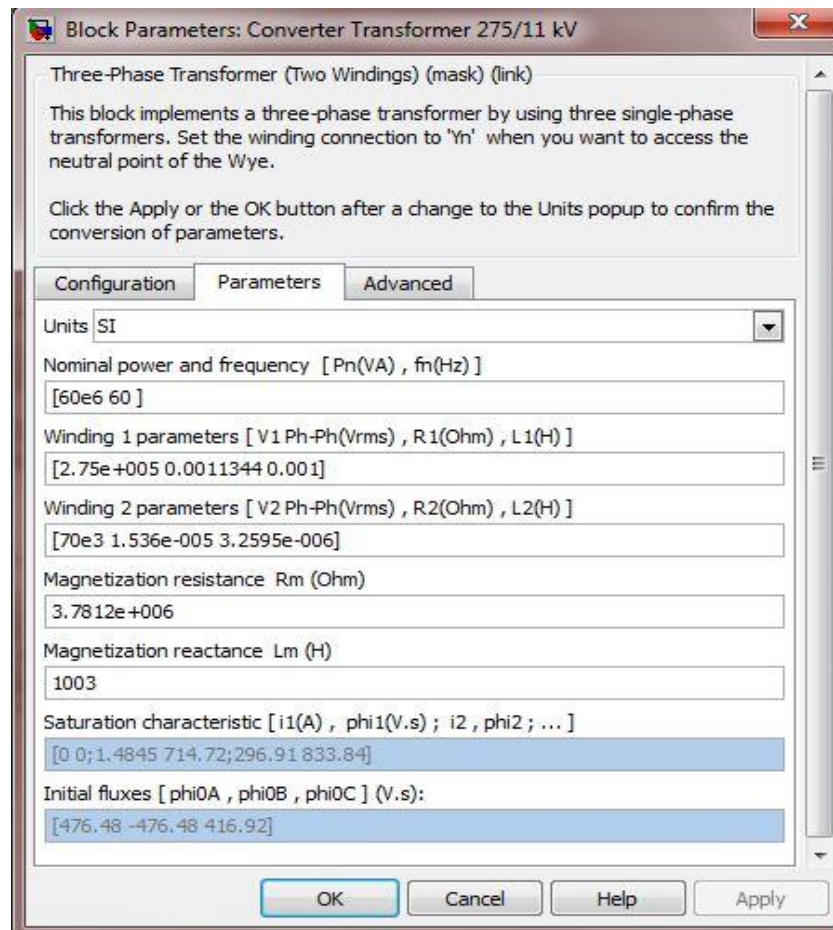
Inductive reactive power QL (positive var):  
100

Capacitive reactive power Qc (negative var):  
100

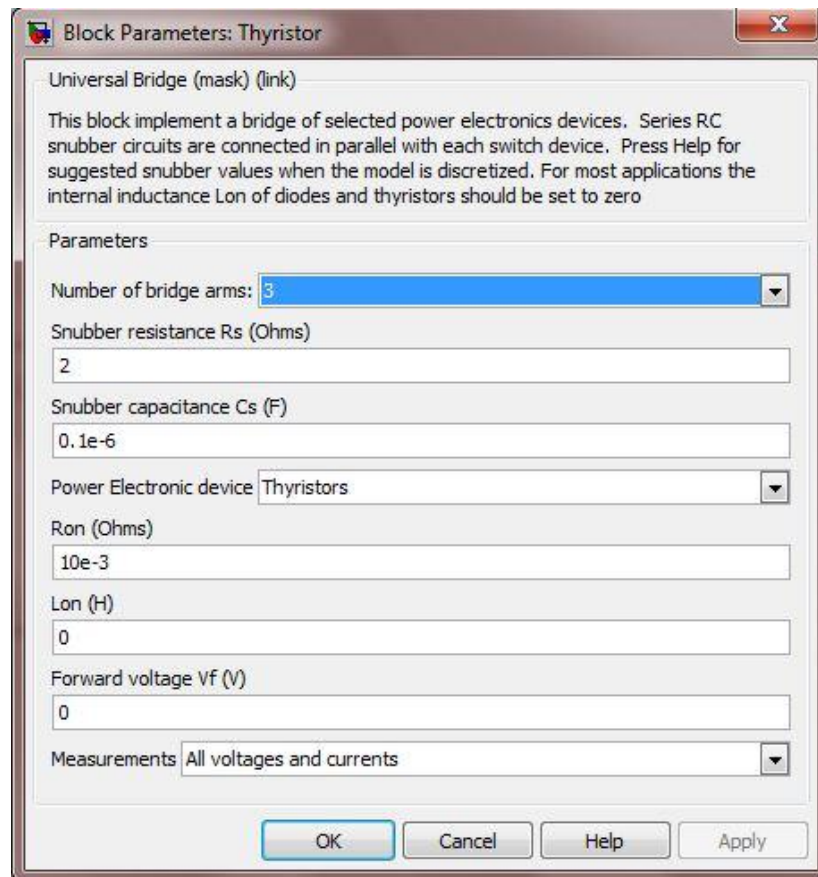
Measurements: None

OK Cancel Help Apply

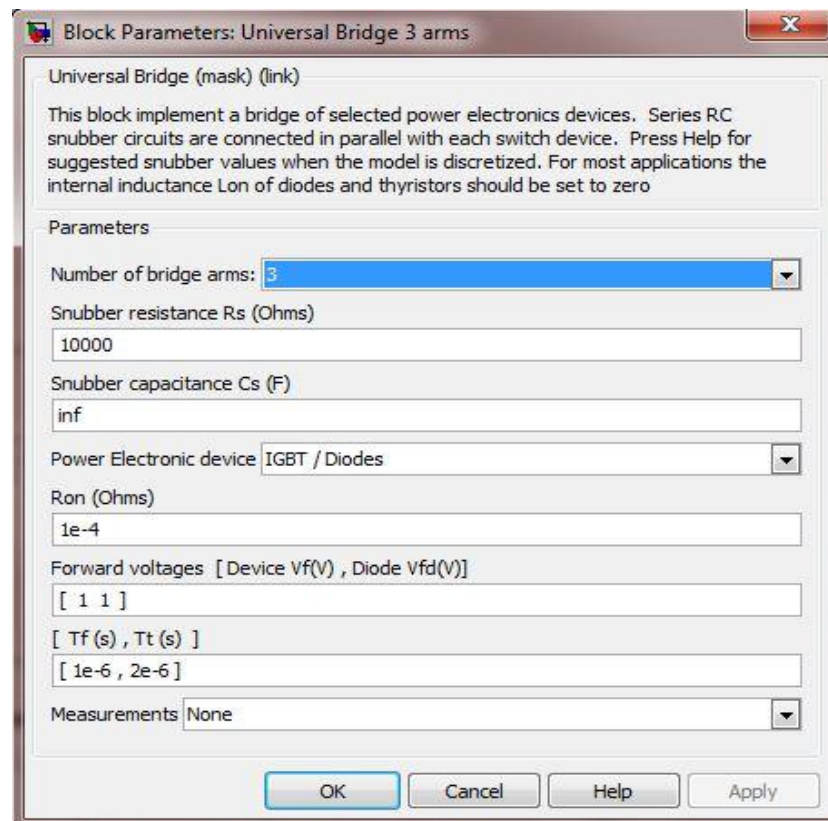
Load at AC network 1



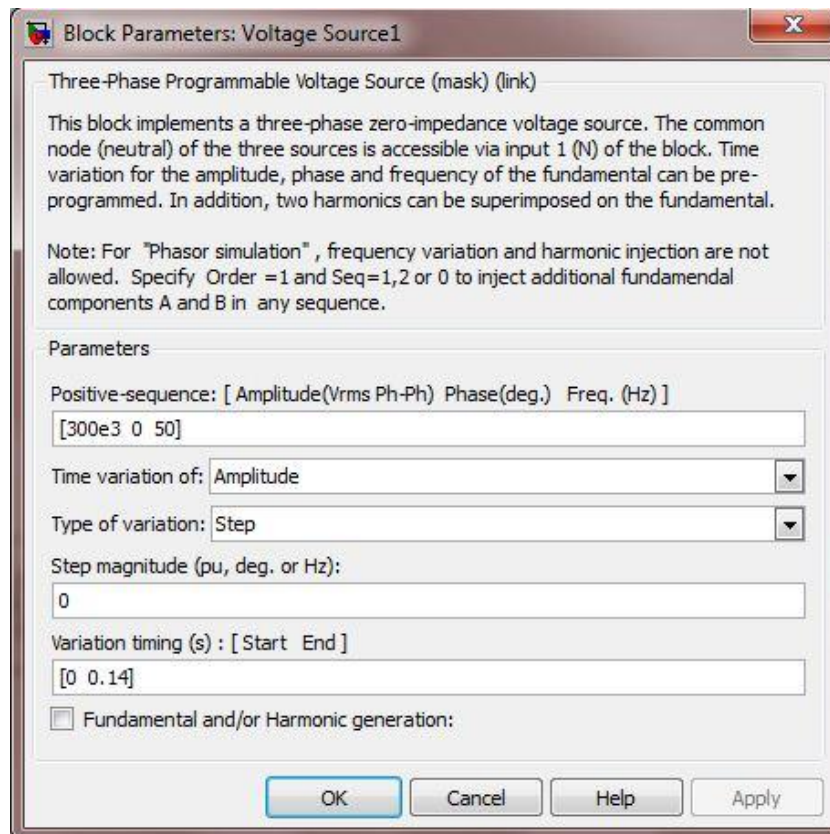
Converter Transformer



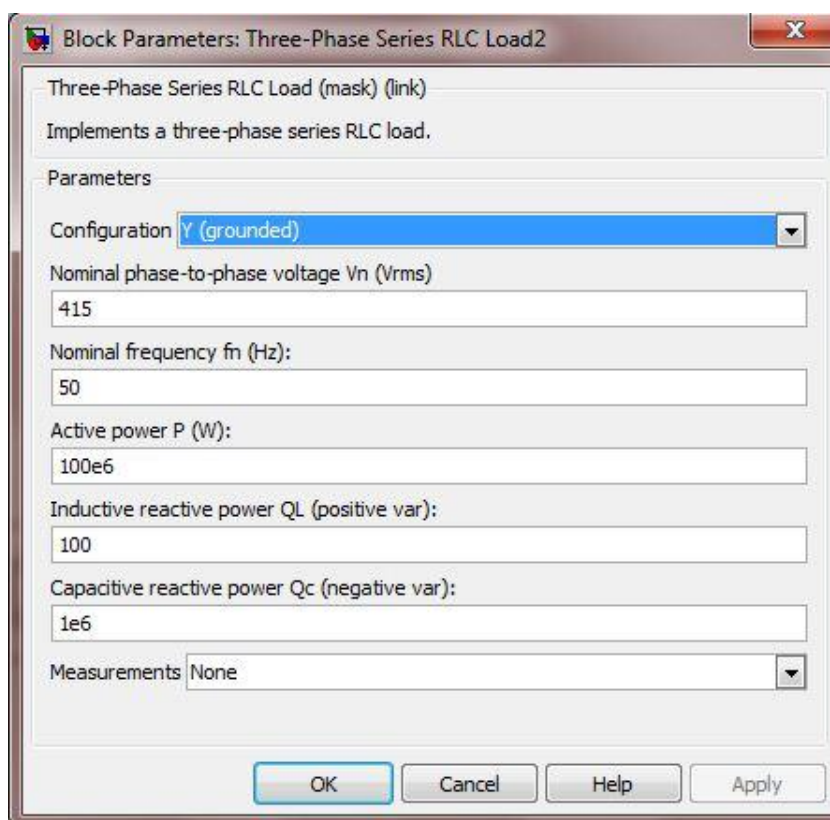
Thyristor



Insulated gate bipolar transistor (IGBT)



Voltage source at AC network 2



Load at AC network 2